A FUZZY LOGIC ALGORITHM FOR HEART RATE MONITORING

by

NIK MUHAMAD LUKMAN NULHAKIM BIN NIK ABDULLAH

FINAL PROJECT REPORT

Submitted To the Department of Electrical & Electronic Engineering

In Partial Fulfillment of the Requirements

for the Degree

Bachelor of Engineering (Hons)

(Electrical & Electronic Engineering)

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

CERTIFICATION OF ORIGINALITY

This to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NIK MUHAMAD LUKMAN NULHAKIM
BIN NIK ABDULLAH

ABSTRACT

The heart rate of a person was monitored based on heart resting rate and results or readings taken from the wireless device. The heart rate was classified using fuzzy logic. The input data to be used in developing the membership function. Normal heart rate was different between genders and varies from individuals to other individuals. Fuzzy logic was one of the current technologies that allow description of the desired system behavior using common language. Its membership function assumes the value interval from [0, 1]. A total of three simulation was done. The first simulation was developed based on the simple heart rate classification that was normal from 60 bpm to 100 bpm, Tachycardia for fast heart rate that was more than 100 bpm and Bradycardia for slow heart rate that was less than 60 bpm. The second simulation was developed to classify the resting heart rate for men and women based on their age and fitness level that include athletic, excellent, good and etc. The third simulation was an upgrade from the second simulation. The membership function for heart rate was increase for further precise classification and a graphic user interface (GUI) was introduce to increase the efficiency and interaction. The project was able to develop the membership function and implement in PC. The project was aims to minimize the time to interpret the heart rate condition so that the monitoring process was better. The project was implemented using MATLAB using Fuzzy Logic Toolbox™.

ACKNOWLEDGEMENT

Thanks to Allah the Almighty. Thanks to Universiti Teknologi PETRONAS, my supervisor and all who supported me for guidance, assistance and help throughout my project.

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HR	Heart rate
FIS	Fuzzy Inference System
GUI	Graphic User Interface

CHAPTER 1
INTRODUCTION

1.1. Background

Fuzzy logic is one of the current technologies that allow description of the desired system behavior using common language. It is developed by Lotfi A. Zadeh in 1965. It is a problem solving control system methodology based on "degree of truth" rather than "true" or "false". Its membership function assumes the value interval from [0,1] where '0' is completely false and '1' is completely true, thus interpreting the common language for example, very fast, fast, normal and so on into numbers. Fuzzy logic has been applied in many fields mostly in control system.

The project is to develop an algorithm for fuzzy logic to monitor the physiological signs of an individual specifically heart rate according to age and gender. The input data used to develop the membership function is taken from the reading of Zigbee module device. Then the data is processed using fuzzy logic algorithm in the Fuzzy Logic Toolbox™. The project will benefit the medical world especially in faster monitoring process.

The Zigbee module device is a device that is capable to monitor the heart rate and body temperature using wireless technology. It is developed by H. Daud, N. F. I. Gulcharan et al. The device is worn on the body at lying down position and the reading is transmitted to a wireless transceiver Zigbee at a remote location.

The Zigbee module device utilize the Zigbee X-bee-pro and Zigbee SKXBEE. The data from the sensors is process using the Arduino Uno microprocessor.

1.2. Problem Statement

The heart rate of a person is monitored based on the resting heart rate and the results taken from the wireless device are in terms of a 2 digit numbers with the corresponding description such as very fast, fast and so on. To minimize the time in interpreting the heart rate condition, a fuzzy logic algorithm will be designed to simplify by coding to interpret and automate results. The automation process will reduce the time of classifying the heart condition.

1.3. Objective

1. To develop a membership function for fuzzy logic using the heart rates data taken from a wireless body worn device called Zigbee module device.
2. To implement the algorithm in the PC.
3. To verify results of monitoring.

1.4. Scope of Study

The scopes of study for the project are as below

1. The theory of heart rate and the classification used in medical field.
2. The theory of fuzzy set and fuzzy logic in monitoring application.
3. The working principle of wireless Zigbee module device and use the module output as the input for fuzzy logic algorithm.
4. Apply the fuzzy logic algorithm in MATLAB using Fuzzy Logic Toolbox™.
5. Apply the fuzzy logic algorithm to classify the heart rate based on gender, six age groups and seven resting heart conditions.

1.5. Relevancy of The Project

The classification of heart rate is important in the medical world. Many diseases are diagnosed using heart rate and with a faster classification using fuzzy logic, the time to analyze the heart rate will be minimized.

1.6. Feasibility of The Project

The project is feasible and manageable within the period of two semesters. During the first semester, the project was focused on the theory on heart, heart rate and fuzzy logic in monitoring application. Several applications was reviewed to gain an adequate understanding on the project. While during the second semester, the fuzzy logic algorithm was developed using Fuzzy Logic Toolbox™ and series of testing and experimenting was done to classify the heart rate based on the desired classification. The period of two semesters is feasible as EEE student have the basic understanding on MATLAB and many of research have been done using fuzzy logic for the monitoring application.

CHAPTER 2
LITERATURE REVIEW

2.1. Heart

Heart is a muscular organ found in human body that has a very important function. It pumps blood through the blood vessel found in the circulatory system in human and animal. Heart has four chambers that function to pump blood that is right atrium, right ventricle, left atrium and left ventricle

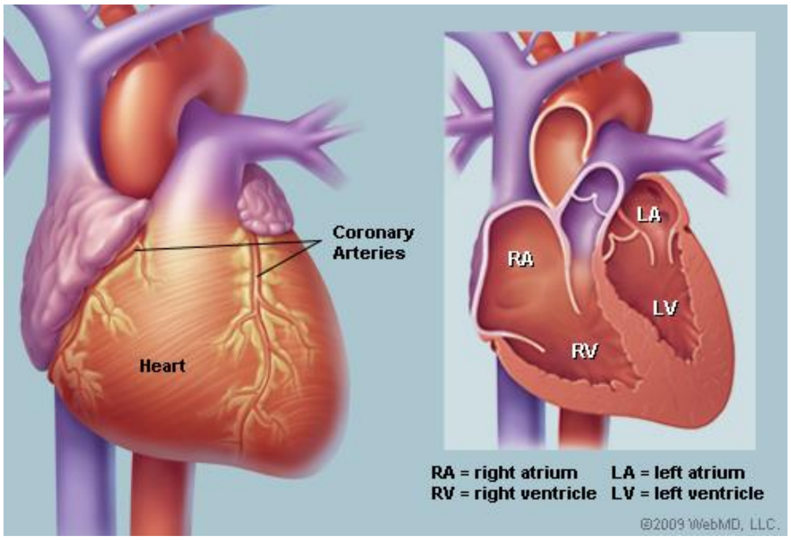

Figure 1: Heart Anatomy [1].

The blood flows from veins into the right atrium and pump to the right ventricle. Then the blood flows is pump from right ventricle into the lungs where carbon dioxide is exchange with oxygen. The oxygenated blood flows back into the heart through the left atrium and pump to the left ventricle. Finally the blood is pump to all part of the body through the aorta [1].

The first functional organ in the early development of embryo is the heart and the heart start to beat after 21 days of conception [2].

2.2. Heart Rate

Heart rate or pulse is the number of the heart beats per minutes (bpm). Normal heart rate is different between genders and varies from one individual to another individual. The resting heart rate is normally from 60 bpm to 100 bpm. If a person is cardiorespiratory fit or athletic, the resting heart rate is slower than the average person as the heart is strong and does not have to work hard to pump blood in body [3]. The maximum heart rate can be estimated using formula (1) and (2) [4].

$$HR_{max} = 220 - Age \tag{1}$$

$$HR_{max} = 205.8 - 0.685(Age) \tag{2}$$

There are several factors that affect the heart rate there are temperature, emotion, body size, medication usage, fitness level and activity level. When the temperature is high, the heart rate is high. When the body size is big, the heart rate is high. The usages of medicine such as beta blocker result in low heart rate [5].

The best location to check the heart rate is on the wrists, inside the elbows and the side of the neck. The method to check the heart rate is by pressing the index and middle finger and counts the number pulse for 10 seconds and multiply with 6 for heart rate per minutes.

Fast heart rate that is more than 100 bpm is called Tachycardia and slow heart rate that is less than 60 bpm is called Bradycardia. Irregular heart rate is called Arrhythmia [6].

2.3. Electrocardiogram

Electrocardiogram (ECG) is a test that records the electrical activity of the heart. The wave form of the ECG is used to determine the heart rate, heart rhythm, damage of the heart and the effect of drug and pacemaker to the heart. For a normal person, the result of heart rate should be 60 bpm to 100 bpm and the heart rhythm is consistent and even.

ECG wave contain several component such as:

- Wave
- Segment
- Complex
- Interval

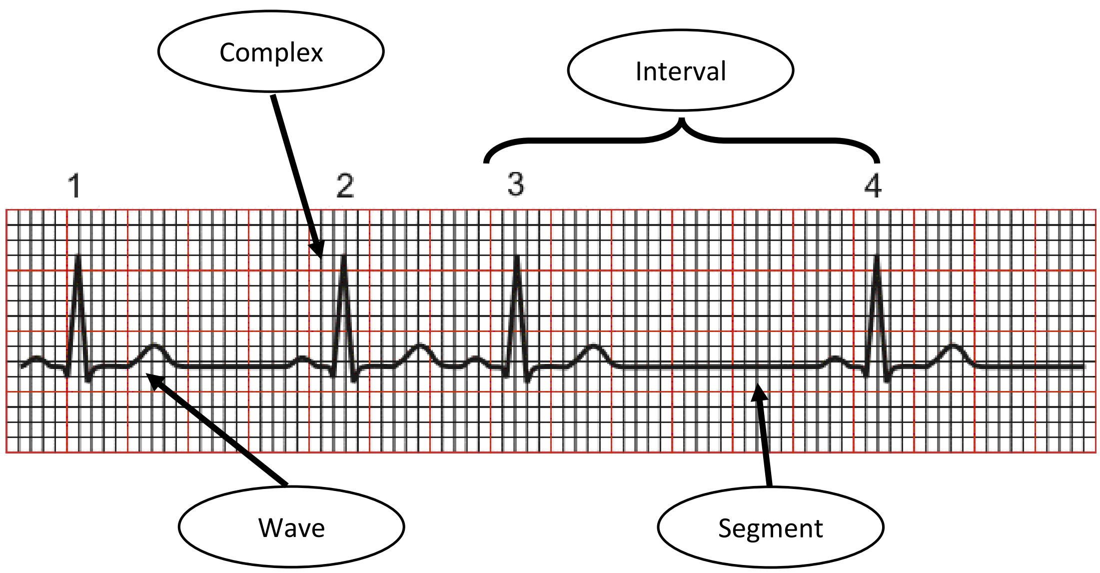

Figure 2: Component of ECG Wave [7].

From the ECG wave, heart rate can be calculated by measuring the interval as in equation (3) [7].

$$HR = \frac{1500}{Number\ of\ Square\ of\ Interval} \tag{3}$$

2.4. Heart Rate Classification

Heart rate can be classified into three categories.

Table 1: Heart Rate Category [6].

Bradycardia	Less than 60 bpm
Normal	60 bpm – 100 bpm
Tachycardia	More than 100 bpm

Heart rate can also be classified based on the workout level.

Table 2: Target Heart Rate for Workout Level [8].

Workout Level	Percentage of Maximum Heart Rate
Resting Zone	50% - 60%
Fat Burning Zone	60% - 70%
Aerobic Zone	70% - 80%
Anaerobic Zone	80% - 90%
Red Line Zone	90% - 100%

Resting Heart rate can be classified based on the gender and fitness[9].

Table 3: Resting Heart Rate for Men

Age	18-25	26-35	36-45	46-55	56-65	65+
Athlete	49-55	49-54	50-56	50-57	51-56	50-55
Excellent	56-61	55-61	57-62	58-63	57-61	56-61
Good	62-65	62-65	63-66	64-67	62-67	62-65
Above Average	66-69	66-70	67-70	68-71	68-71	66-69
Average	70-73	71-74	71-75	72-76	72-75	70-73
Below Average	74-81	75-81	76-82	77-83	76-81	74-79
Poor	82+	82+	83+	84+	82+	80+

Table 4: Resting Heart Rate for Women

Age	18-25	26-35	36-45	46-55	56-65	65+
Athlete	54-60	54-59	54-59	54-60	54-59	54-59
Excellent	61-65	60-64	60-64	61-65	60-64	60-64
Good	66-69	65-68	65-69	66-69	65-68	65-68
Above Average	70-73	69-72	70-73	70-73	69-73	69-72
Average	74-78	73-76	74-78	74-77	74-77	73-76
Below Average	79-84	77-82	79-84	78-83	78-83	77-84
Poor	85+	83+	85+	84+	84+	84+

It is shown in the table above that men have a lower resting heart rate compared to women. It also showed that as the heart rate is higher, the fitness level is lower.

2.5. Fuzzy Logic Theory

2.5.1. Crisp Set vs. Fuzzy Set

In crisp set, an element is either member or non-member. A simple example of crisp set is the type of bird - chicken, duck, pigeon, owl, ostrich and macaw. Chicken, duck and ostrich is the member of non-flying bird, while pigeon, owl and macaw is the member of flying bird [10].

In fuzzy set, an element can be partially belongs to a set. The membership value of ‘0’ means that the element does not belong to the set and ‘1’ means that the element belongs to the set. The element can also be assigned with a membership value between ‘0 - 1’ such as ‘0.2’ or ‘0.5’. A simple example of fuzzy set is the classification of how sunny a day is. The way to determine how sunny is the day, is by the percentage of cloud covering the sky [11].

A 100% cloud covering the sky can be assigned with membership function of 1 means a shady day, 75% cloud covering the sky can be assigned with membership value of 0.75 means a shady day, 50% cloud covering the sky can be assigned with membership value of 0.50 means a nice day, 25% cloud covering the sky can be assigned with membership value of 0.25 means a sunny day, 0% cloud covering the sky can be assigned with membership value of 0 means a very bright day.

2.5.2. Fuzzy Logic

Fuzzy logic has several types of membership function such as triangular, trapezoidal, Gaussian, R and L function [12].

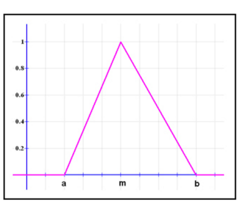

Figure 3: Triangular.

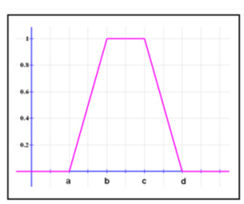

Figure 4: Trapezoidal.

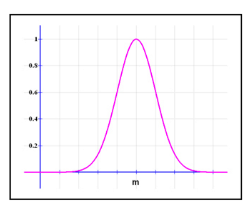

Figure 5: Gaussian.

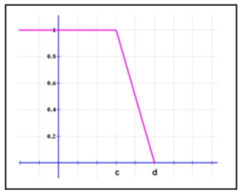

Figure 6: R Function

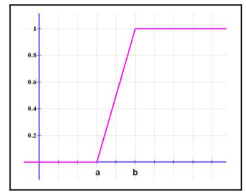

Figure 7: L Function

Fuzzy logic have three basic operations. There are OR, AND and NOT. OR is interpreted as union operation, AND is interpreted as intersection operation and NOT is interpreted as complement operation [13, 14].

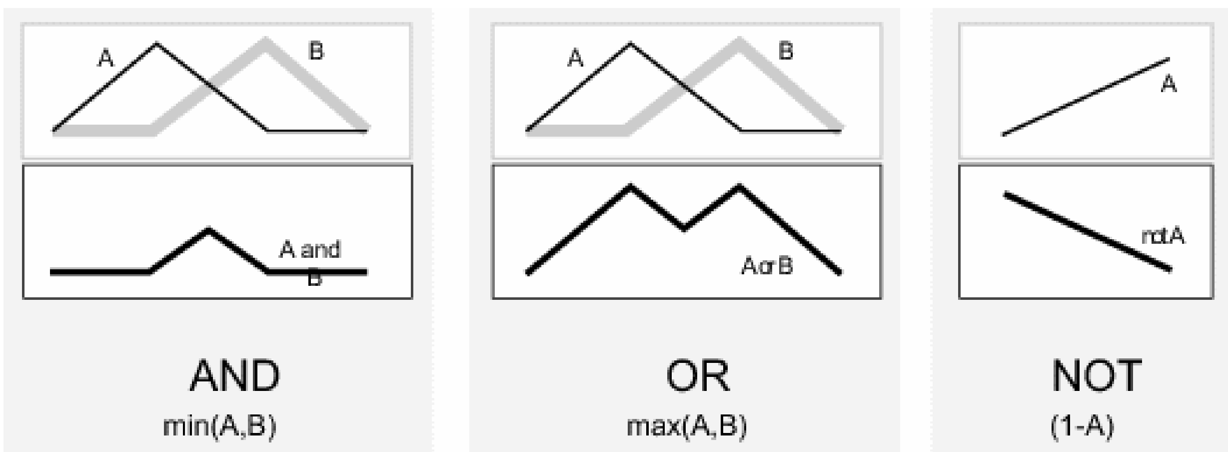

Figure 8: Fuzzy Logic Operation [15].

$$AND = \mu_{A \cap B} = Min\big(\mu_A(x), \mu_B(x)\big) \tag{5}$$

$$OR = \mu_{A \cup B} = Max\big(\mu_A(x), \mu_B(x)\big) \tag{4}$$

$$NOT = \mu_{A^{\complement}} = 1 - \mu_A(x) \tag{6}$$

2.5.3. Fuzzy Inference Systems (FIS)

Fuzzy inference system (FIS) is a process of mapping a given input to an output using fuzzy logic. The mapping process provides a basis which a decision is made. FIS formalize the reasoning process of human language using fuzzy IF-THEN rules.

The IF-THEN rules follow the pattern of "*If x is A, then y is B*". A simple example of FIS is "*If the service is good, even if the food is not excellent, then the tip will be generous*" [12, 15].

FIS consist of four modules that are knowledge base, inference engine, fuzzification and defuzzification. Knowledge base functions as a store for the IF-THEN rules. Inference engine simulates the logic reasoning based on human language by making inference between the inputs and IF-THEN rules. Fuzzification transforms crisp set into fuzzy set input and defuzzyfication transforms fuzzy set output to a crisp output value.

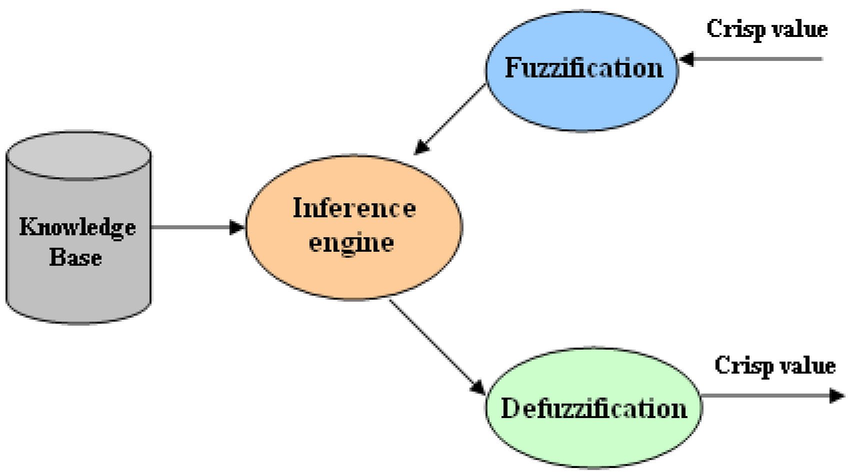

Figure 9: Structure of Fuzzy Inference System [12].

2.5.4. Method of Fuzzy Logic

Fuzzy logic has two most common methods that are Mamdani's method and Takagi and Sugeno's method. Mamdani's method is used when the number of variable is small while Takagi and Sugeno's method is used when the number of variable is large and the logic is complicatied.

Table 5: Advantages of Mamdani's and Takagi and Sugeno's Method [15, 16].

Advantages	
Mamdani's	Takagi and Sugeno's
Simple to build	Suitable to compute
Basic fuzzy method	Can use linear technique to control non-linear system (PID)
Suited for human input	Optimize the output to improve efficiency
Suitable for long delay process	Computationally efficient
Widespread acceptance	Suitable for mathematical analysis

Table 6: Disadvantages of Mamdani's and Takagi and Sugeno's Method [15, 16]

Disadvantages	
Mamdani's	Takagi and Sugeno's
Too simple to control quick process	Not intuitive
Need extra device to increase efficiency when control high frequency input	Higher order is very complex

2.6. MATLAB and Fuzzy Logic Toolbox™

In MATLAB, there is a toolbox call Fuzzy Logic Toolbox™. Fuzzy Logic Toolbox™ has five graphical user interface (GUI) used to perform fuzzy logic [15]. Fuzzy Logic Toolbox™ GUI consists of:

- Fuzzy Inference System (FIS) Editor

  Use to handle and edit number of variable, variable name, defuzzification method and etc.

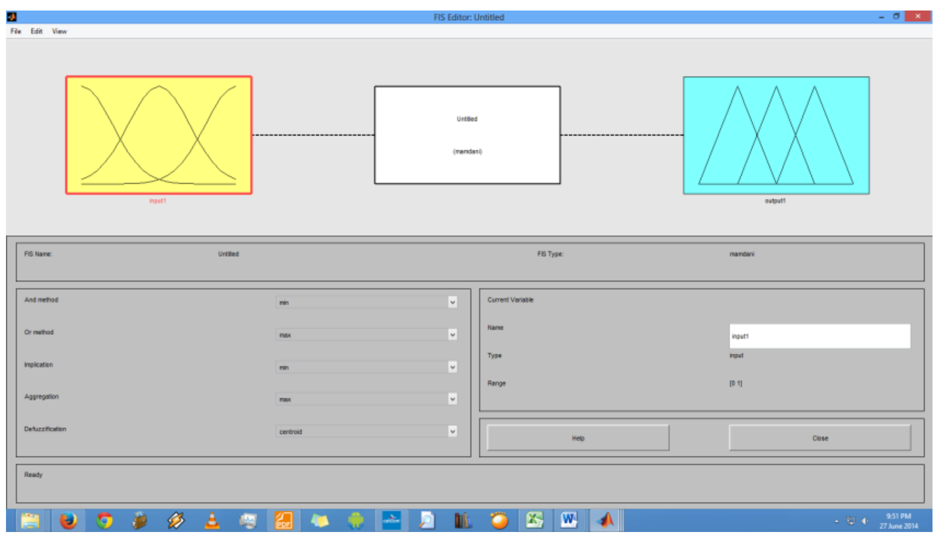

Figure 10: FIS Editor GUI.

- Membership Function Editor

  Use to describe and edit the shapes of the membership functions for each variable

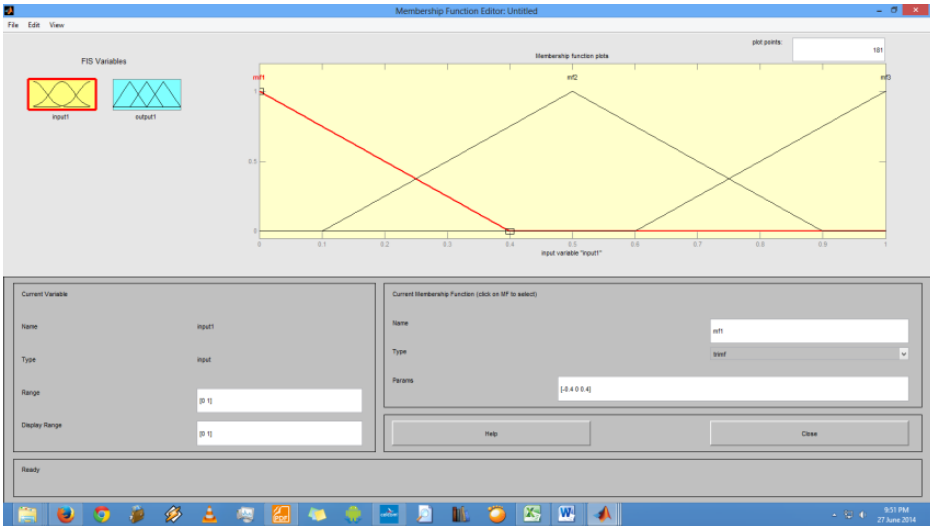

Figure 11: Membership Function Editor GUI.

- Rule Editor

  Use to handle and edit the list of rules that describes the behavior of the system for each variable.

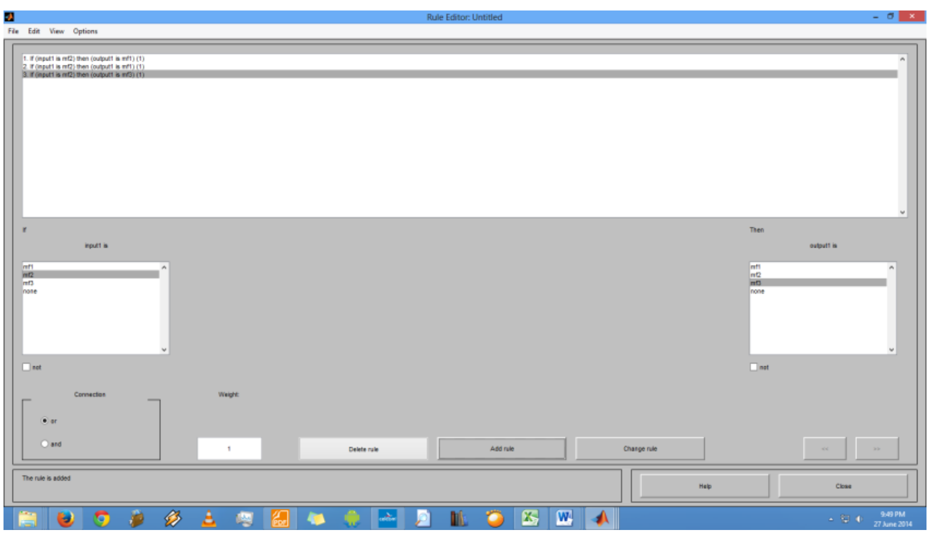

Figure 12: Rule Editor GUI.

- Rule Viewer

  Use to view the fuzzy inference diagram to analyze how membership function shapes influence the results

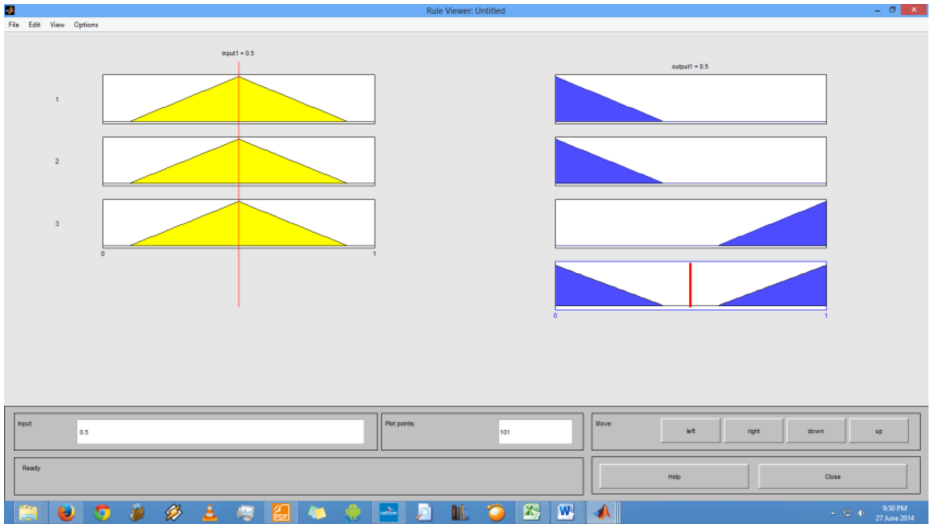

Figure 13: Rule Viewer GUI.

- Surface Viewer

  Use to generate and plots an output of the system.

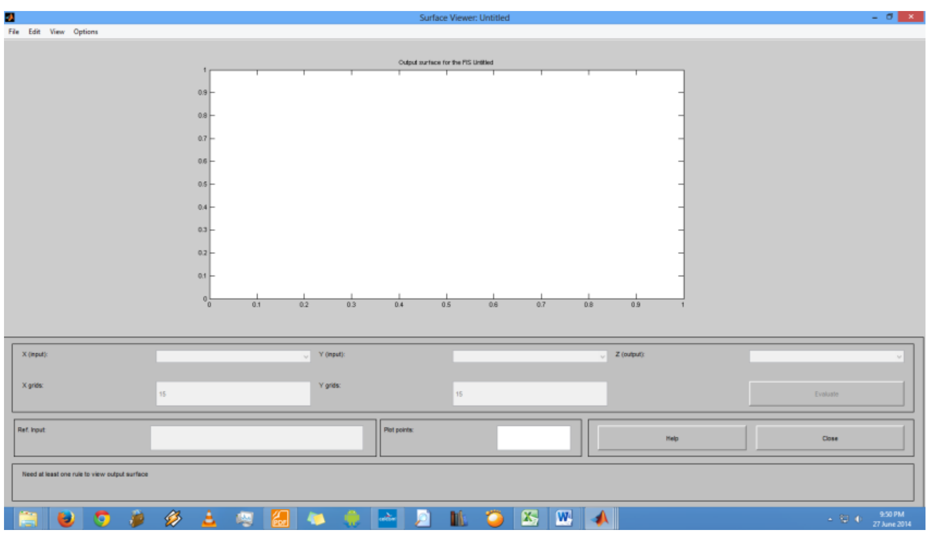

Figure 14: Surface Viewer GUI.

2.7. Existing Fuzzy Logic Application

There are many application of fuzzy logic being implemented in various fields. This is because of its capacity and simplicity. The table below shows several review of fuzzy logic use in medical field.

Table 7: Application of Fuzzy Logic as a Classifier.

Author	Applications	Techniques	Advantages
G. Schaefer, T. Nakashima et al[17].	Diagnose breast cancer.	Mamdani's Method - Thermogram fuzzy classification	Accuracy of 80% comparable with other imaging technique.
E. Sivasankar and R.Rajesh [18].	Diagnose severity of appendicitis.	Mamdani's Method	High accuracy tested with 2230 data sets.
A. Yilmaz and K. Ayan[19].	Cancer risk analysis.	Modified Mamdani's fuzzy logic.	High accuracy.
D. F.Abang Sazali[10].	Classification of Hep-2 Cell Images	Standard score ranges of ANA fluorescence intensity	High accuracy of classification.

2.8. Zigbee Module Device

The data use in the project is taken from a wireless module device. It is capable to monitor the heart rate and body temperature using wireless technology (Zigbee). It is developed by H. Daud, N. F. I. Gulcharan et al. The device is worn on the body at lying down position and the reading is transmitted to a wireless transceiver Zigbee at a remote location.

The Zigbee network used in the project is based in the IEEE 802.15.4 protocol. It is cheap, energy saving and interpersonal communication. The operation of the device start from the data from sensors gathered by an Arduino Uno microcontroller and being transmitted wirelessly from Zigbee Xbee-pro to Zigbee SKXBEE on the user PC. The sensor used to determine the heart rate in the project is a combination of an LED and a photodiode. The sensor is placed on a fingertip and the variance of the volume of blood determine the heart rate of the person.

The measurement of the heart rate is unstable at the first 10^{th} second of the reading before it begin steady [20].

CHAPTER 3
METHODOLOGY

3.1. Project Flow Chart Final Year Project 1

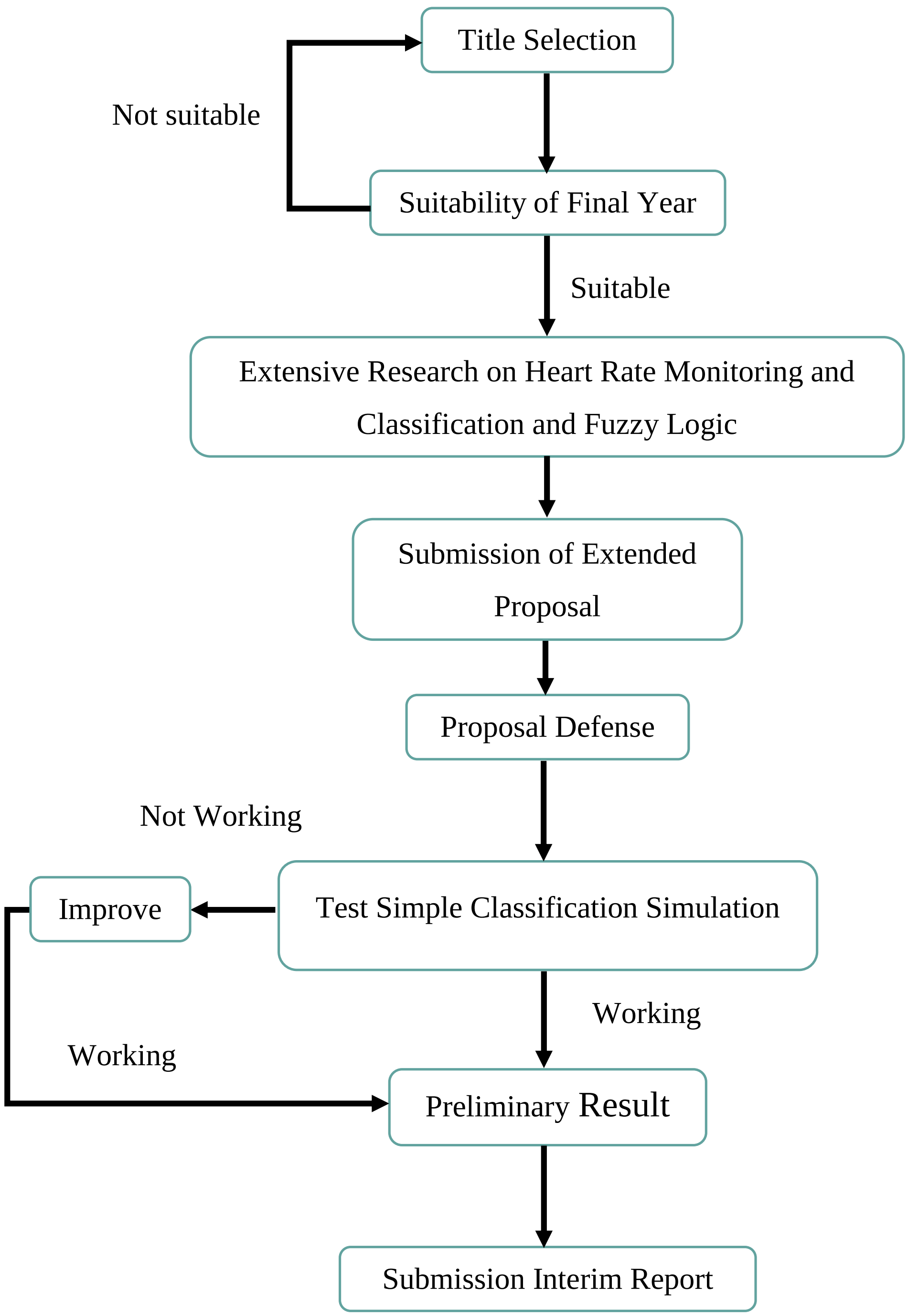

Figure 15: Project Flow Chart for Final Year Project I.

3.2. Project Activities Final Year Project 2

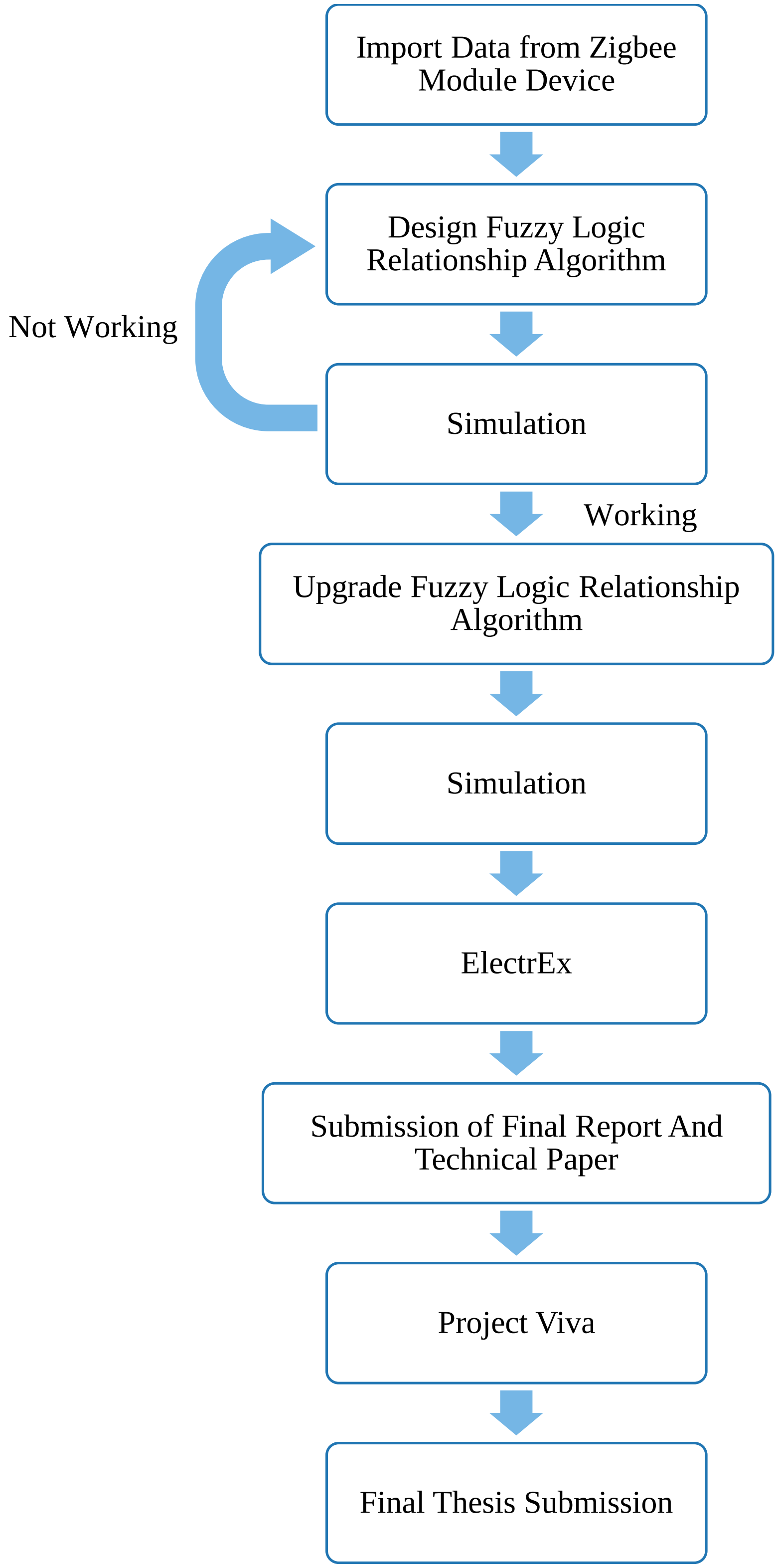

Figure 16: Project Flow Chart for Final Year Project II.

3.3. Gantt Chart

Table 8: Final Year Project I Gantt Chart.

Task/Week	FYP I													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Title Selection and Confirmation >Project Conceptualization		◊												
2. Literature Review >Review Heart Rate Theory >Review Fuzzy Logic Theory >Review Fuzzy Logic Classification Technique						◊								
3. Extended Proposal Writing >Outline Problem Statement >Define Objective and Narrow Scope of Study >Writing Literature Review >Identify Methodology						◊								
4. Extended Proposal Submission						◊								
5. Preparation for Proposal Defense									◊					
6. Proposal Defense and Progress Evaluation									◊					
7. Interim Report Writing >Define Membership Function >Test Simple Classification														◊
8. Submission of Interim Report Draft													◊	
9. Interim Report Submission														◊

◊	Key Milestone

Table 9: Final Year Project II Gantt Chart.

Task/Week	FYP II													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Heart Rate Data Acquisition **>Zigbee Module Data Acquisition**														
2. Classification **>Design Membership Function for Heart Rate Classification Using Fuzzy Logic Toolbox™**					◊									
3. Simulation **>Run Simulation and Verify The Result**											◊			
4. Progress Report Writing **>Update Results And Findings Into Interim Report**														
5. Progress Report Submission								◊						
6. Preparation for ElectrEx **>Compile All Results And Findings** **>Design Poster**											◊			
7. ElectrEx **>Poster Presentation** **>Present Latest Progress And Result**											◊			
8. Final And Technical Report Writing **>Include Final Results And Findings** **>Include Recommendation For Future Development**													◊	
9. Final And Technical Report Submission													◊	
10. Preparation for Project VIVA														
11. Project VIVA														◊

◊	Key Milestone

3.4. Project Schedule

The Planned schedule for Final Year Project I is below.

Table 10: Project Due Date For Final Year Project I

Submission	Due Date
Extended Proposal	27-Jun-14
Proposal Defense	14 – 18 Jul-14
Draft Interim Report (Hardcopy)	14-Aug-14
Interim Report	22-Aug-14

The Planned schedule for Final Year Project II is below.

Table 11: Project Due Date For Final Year Project II

Submission	Due Date
Progress Report	12-Nov-14
ELECTREX	3-Dec-14
Draft Final Report (Hardcopy)	15-Dec-14
Final Report	22-Dec-14
Technical Report	22-Dec-14
Viva	29 – 31-Dec-14
Final Report (Hard Cover)	26-Jan-15

3.5. Tools and Software

1. MATLAB R2011

   Use to process heart rate and store the data.

2. Fuzzy Logic Toolbox™

   Use to construct the algorithm for fuzzy logic.

3. Zigbee Module Device

   Use to get resting heart rate from the patients.

4. Microsoft Office 2013

   Use to write report, handle the data and analysis.

CHAPTER 4
RESULT AND DISCUSSION

4.1. First Simulation

Heart rates are classified into three categories: tachycardia, normal and bradycardia. There are two input variables in FIS and one output. The simulation is shown in figure 17, 18 and 19.

Input:

1. Gender
2. Heart Rate

Output:

1. Heart Condition

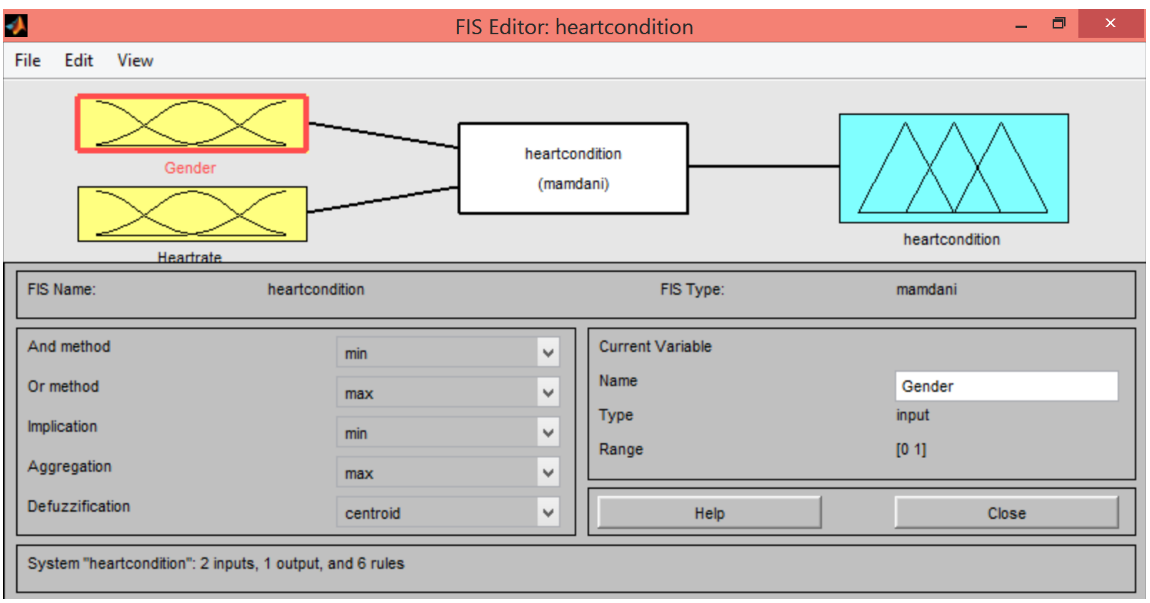

Figure 17: FIS Editor For Heart Condition.

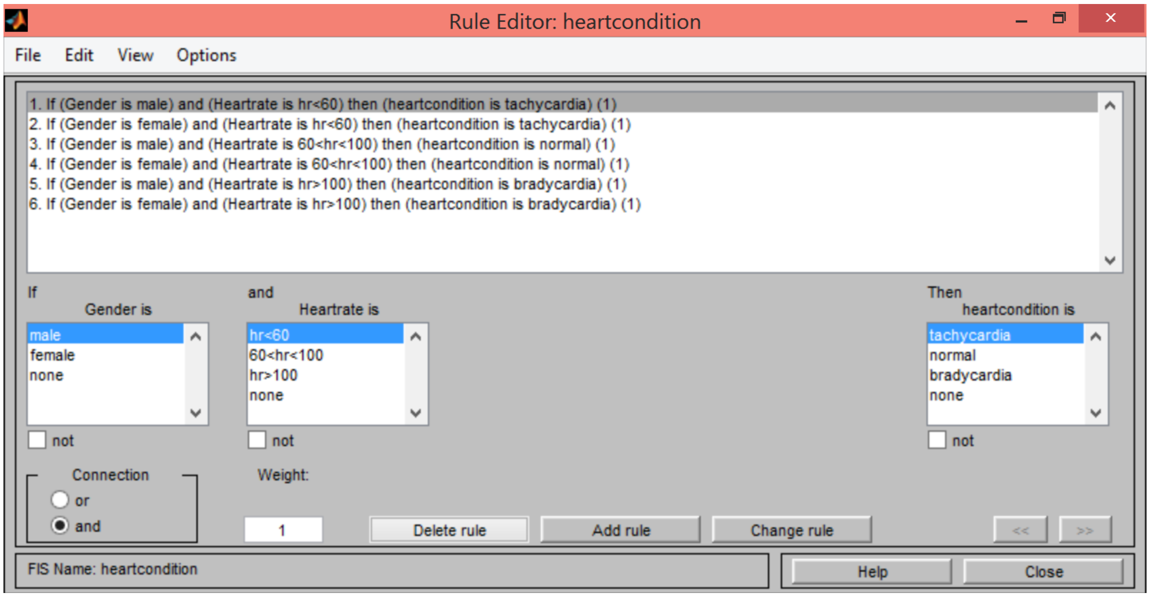

Figure 18: Rule Editor For Heart Condition.

Figure 18 show the rule used to classify the heart rate.

i. *If (Gender is male) and (Heartrate is hr<60) then (heartcondition is tachycardia)*
ii. *If (Gender is male) and (Heartrate is 60<hr<100) then (heartcondition is normal)*
iii. *If (Gender is male) and (Heartrate is hr>100) then (heartcondition is bradycardia)*
iv. *If (Gender is female) and (Heartrate is hr<60) then (heartcondition is tachycardia)*
v. *If (Gender is female) and (Heartrate is 60<hr<100) then (heartcondition is normal)*
vi. *If (Gender is female) and (Heartrate is hr>100) then (heartcondition is bradycardia)*

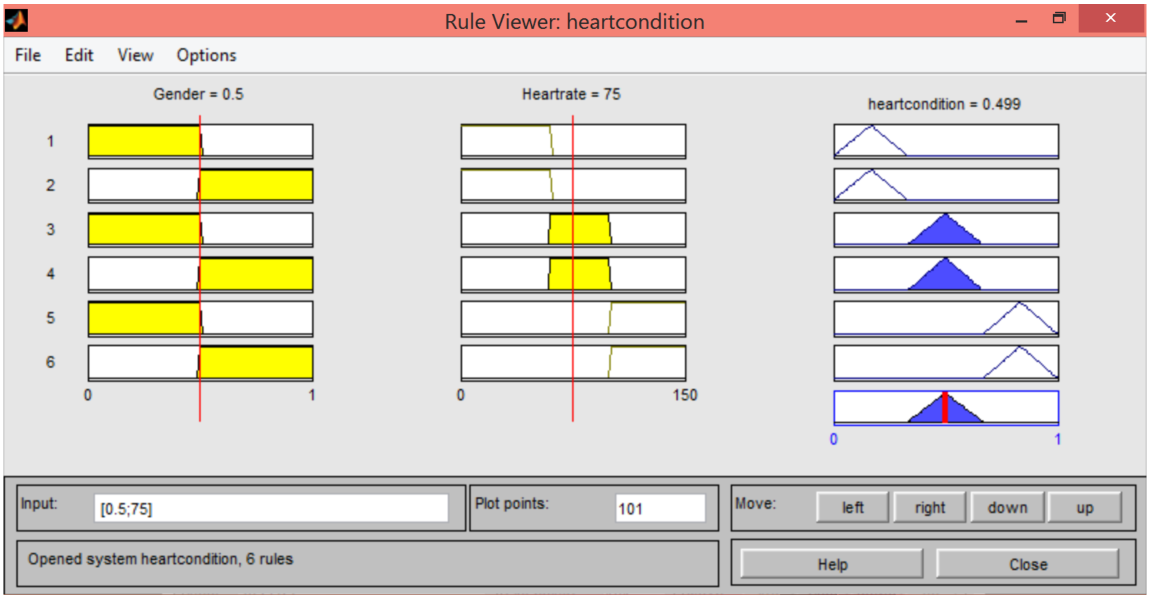

Figure 19: Rule Viewer For Heart Condition.

Figure 19 show how the inputs affect the output based on the rule set in rule editor.

4.2. Second Simulation

Resting heart rates are classified into five categories: athlete, excellent, good, average and poor. There are three input variables in FIS and one output. The simulation is shown in figure 20, 21 and 22.

Input:

1. Gender
2. Age
3. Heart Rate

Output:

2. Condition

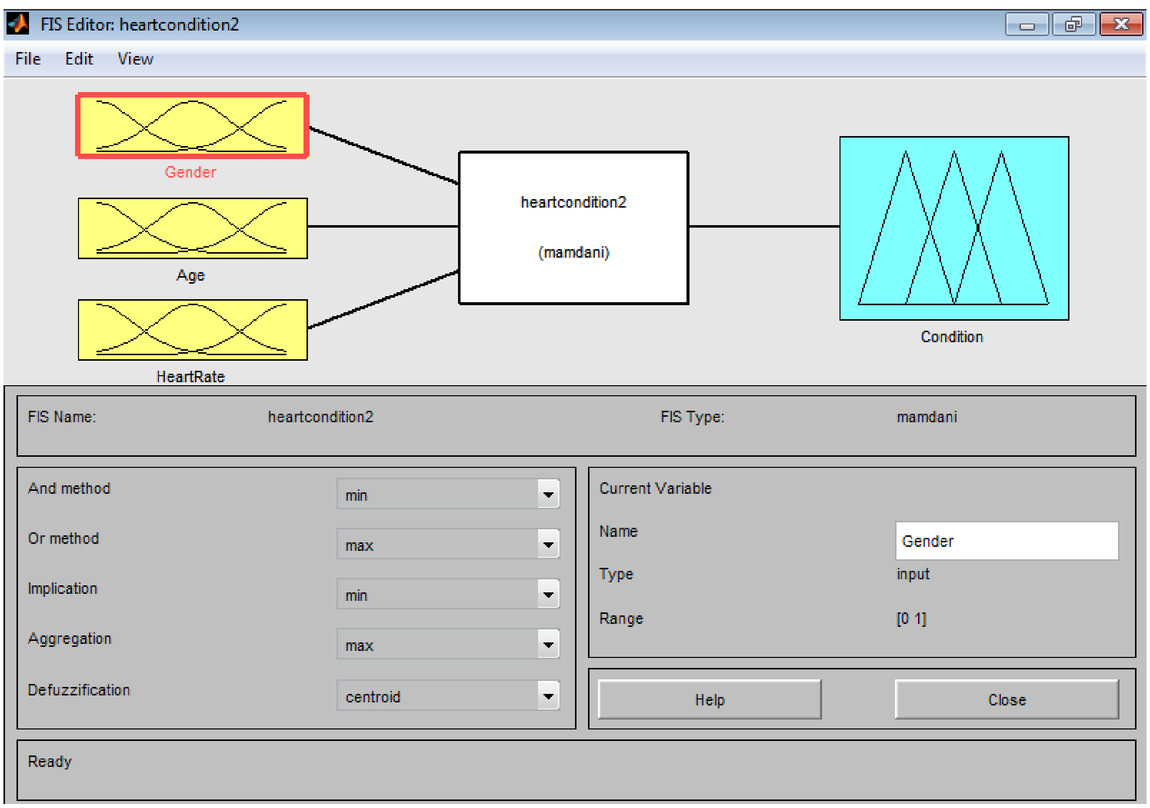

Figure 20: FIS Editor For Resting Heart Rate Classification.

The process used the classification from the resting heart rate table for both genders [9]. The membership value for gender is 0 for male and 1 for female. There are six classes of age from 18 to more than 65 years old and there are 36 membership function used in ‘HeartRate’ input. All the membership type use the trapezoidal shape.

There are five membership function in ‘Condition’ output and the membership values for each membership function is shown as below.

Table 12: Membership Function of ‘Condition’ Output

Membership Function	Membership Type	Membership Value	Output
Athlete	Trimf	0.0 – 0.2	0.1
Excellent	Trimf	0.2 – 0.4	0.3
Good	Trimf	0.4 – 0.6	0.5
Average	Trimf	0.6 – 0.8	0.7
Poor	Trimf	0.8 – 1.0	0.9

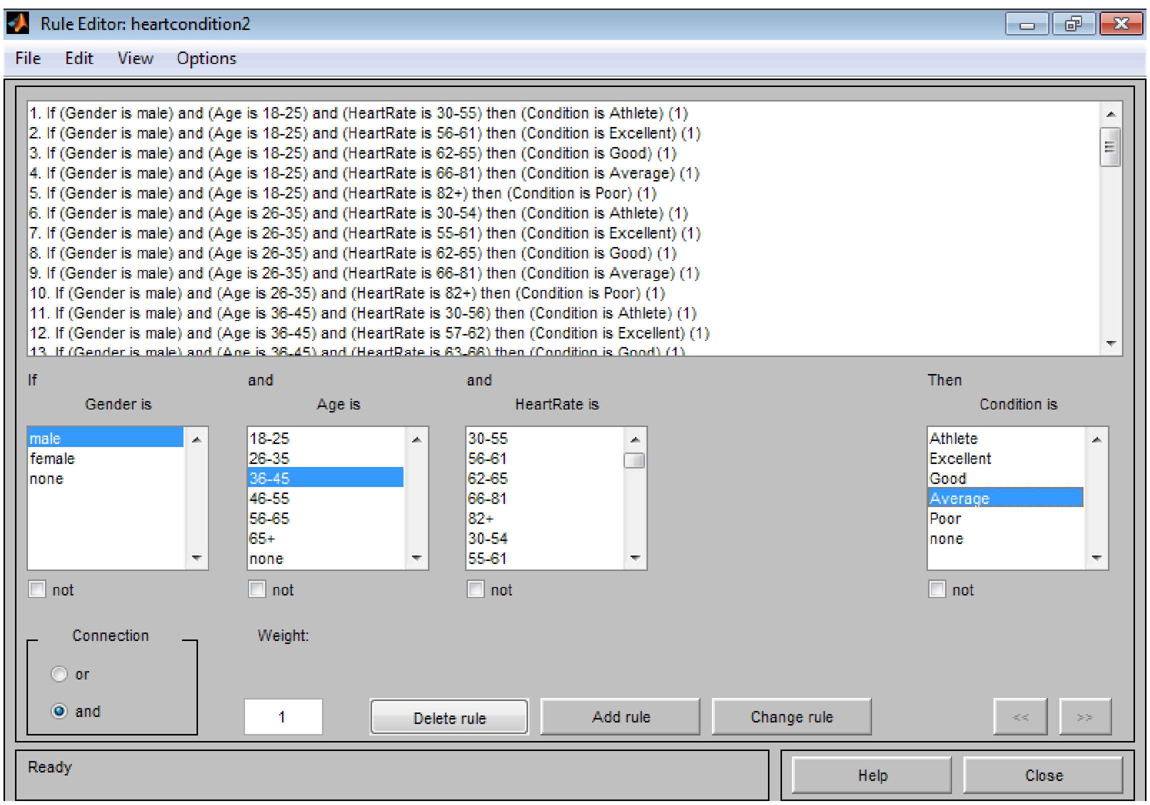

Figure 21: Rule Editor For Resting Heart Rate Classification.

Figure 21 show the rule editor for resting heart rate classification. There are in total of 60 rules used to classify the resting heart rate.

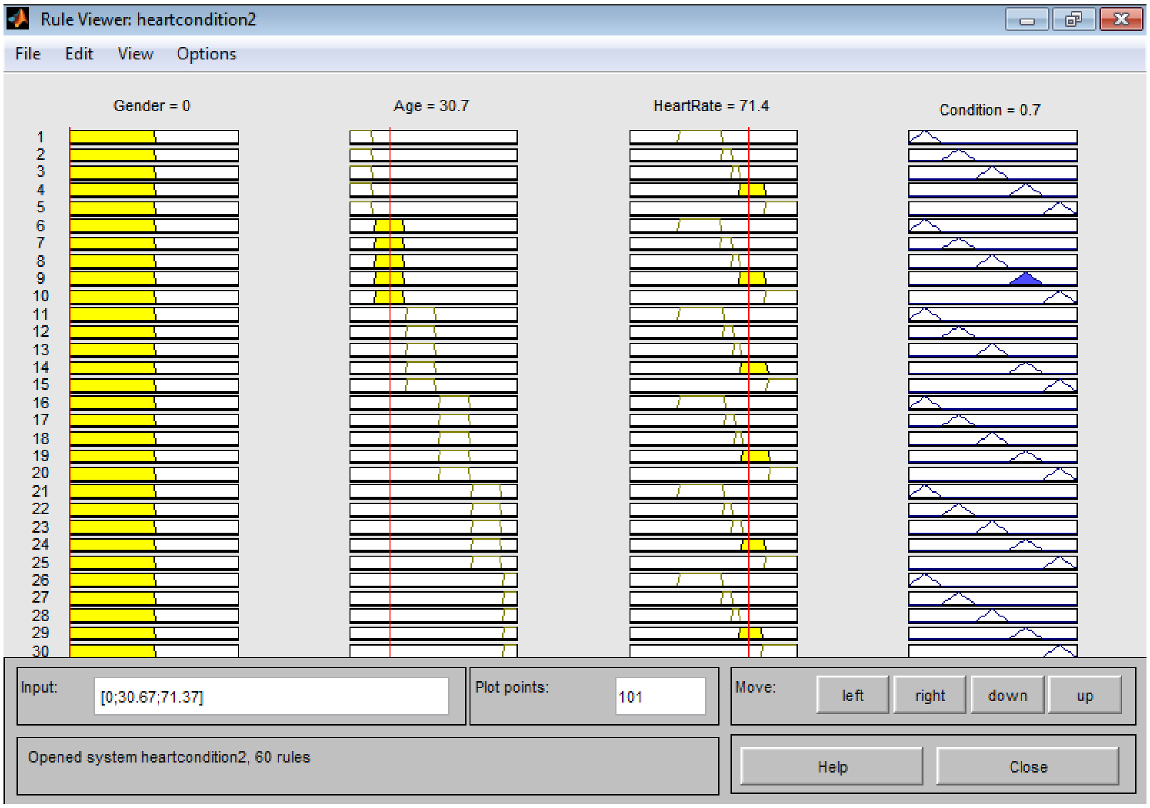

Figure 22: Rule Viewer For Resting Heart Rate Classification.

Figure 22 show the rule viewer for resting heart classification. The example of classification shown above is:

<u>Input:</u>	Output:
Gender = Male	Condition = Average
Age = 30.7	
Heart Rate = 71.4 bpm	

From the rule viewer, the simulation works according to the classification set in the membership function in table 12.

4.3. Third Simulation

In the third simulation, a Graphic User Interface was used for a better interaction between the user and the system. The resting heart rates are classified into seven categories: athlete, excellent, good, above average, average, below average and poor according to table 3 and 4. There are two input variables in FIS and one output. The simulation is shown in figure 23, 24, 25, 26, 27, 28, 29, 30 and 31.

Input:

1. Age
2. Heart Rate

Output:

3. Condition

The fuzzy logic algorithm was separated into 2 categories. There are the algorithm for men and women.

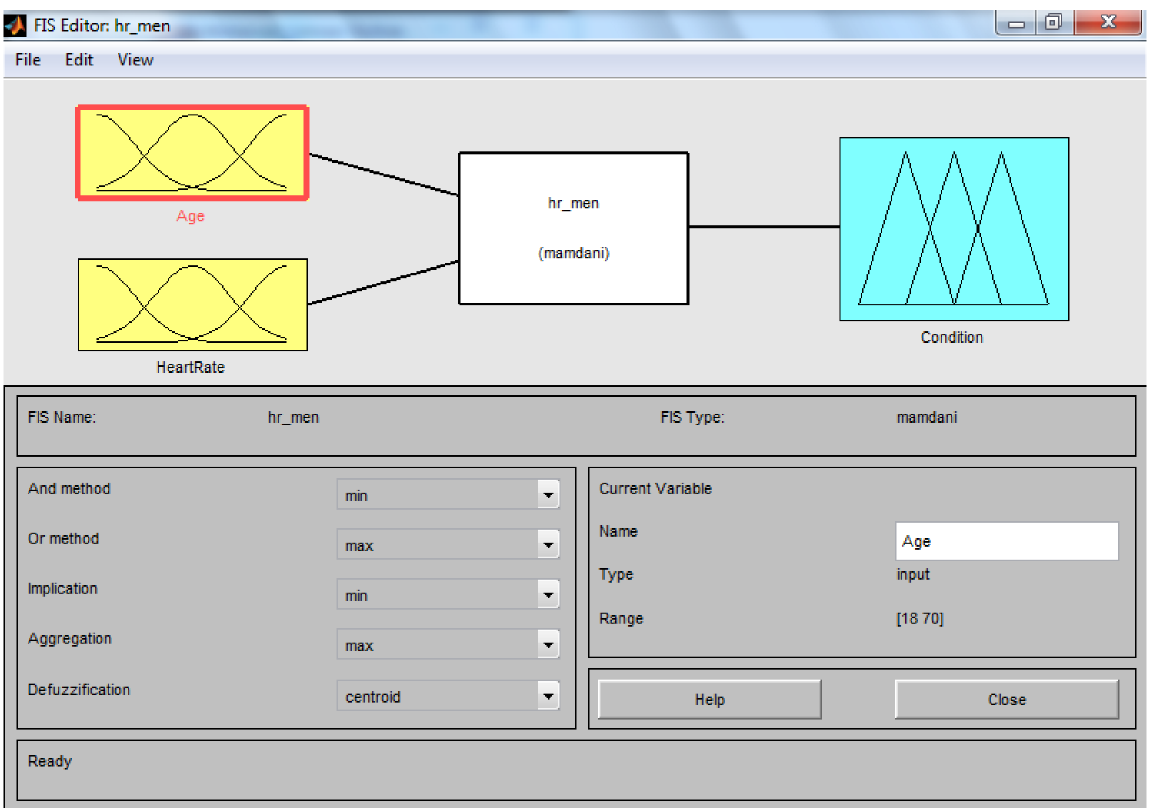

Figure 23: FIS Editor For Men Heart Rate Classification.

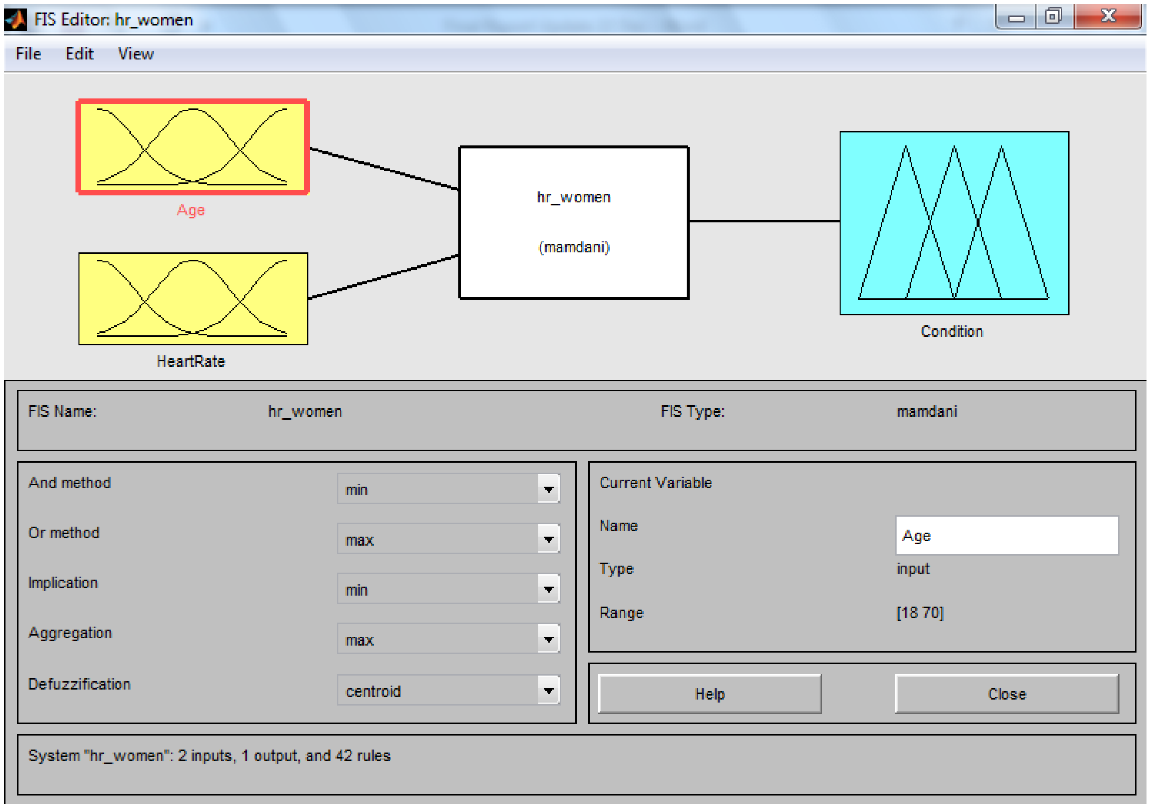

Figure 24: FIS Editor For Women Heart Rate Classification.

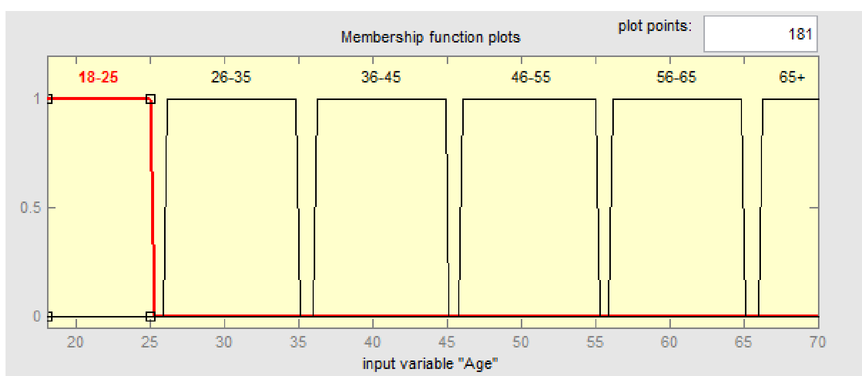

Figure 25: Membership Function For Age.

In figure 25, six membership function of was used. The shape of membership function used was trapezoidal due to their simplicity and the range of ‘Age’ used was from 18-70 years old. Figure 26 shows the membership function for heart rate input. There were in total 42 membership function. Due to the closeness of range between the classes for each age categories, the membership function appear to be overlapping.

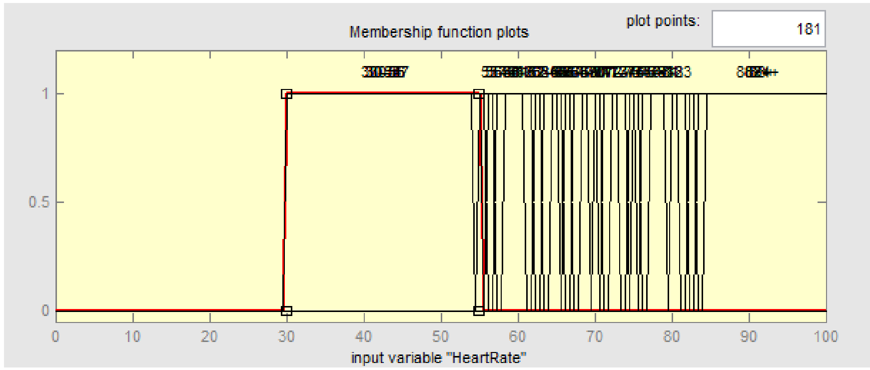

Figure 26: Membership Function For Heart Rate.

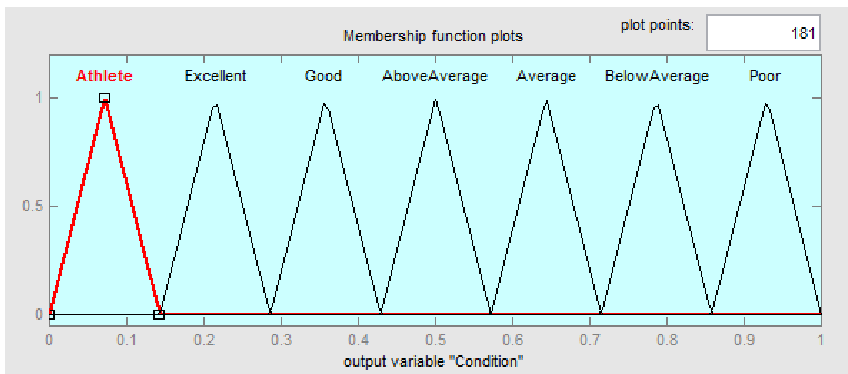

Figure 27: Membership Function For ‘Condition’ Output.

Figure 27 shows the membership function for the output. Ranges from 0 to 1, the membership function has seven classes. Both fuzzy logic algorithm for men and women used the same membership function.

Table 13: Membership Function of ‘Condition’ Output.

Membership Function	Membership Type	Membership Value	Output
Athlete	Trimf	0.0 – 0.143	0.0715
Excellent	Trimf	0.143 – 0.286	0.2145
Good	Trimf	0.286 – 0.429	0.3575
Above Average	Trimf	0.429 – 0.572	0.5005
Average	Trimf	0.572 – 0.715	0.6435
Below Average	Trimf	0.715 – 0.858	0.7865
Poor	Trimf	0.858 – 1.0	0.9295

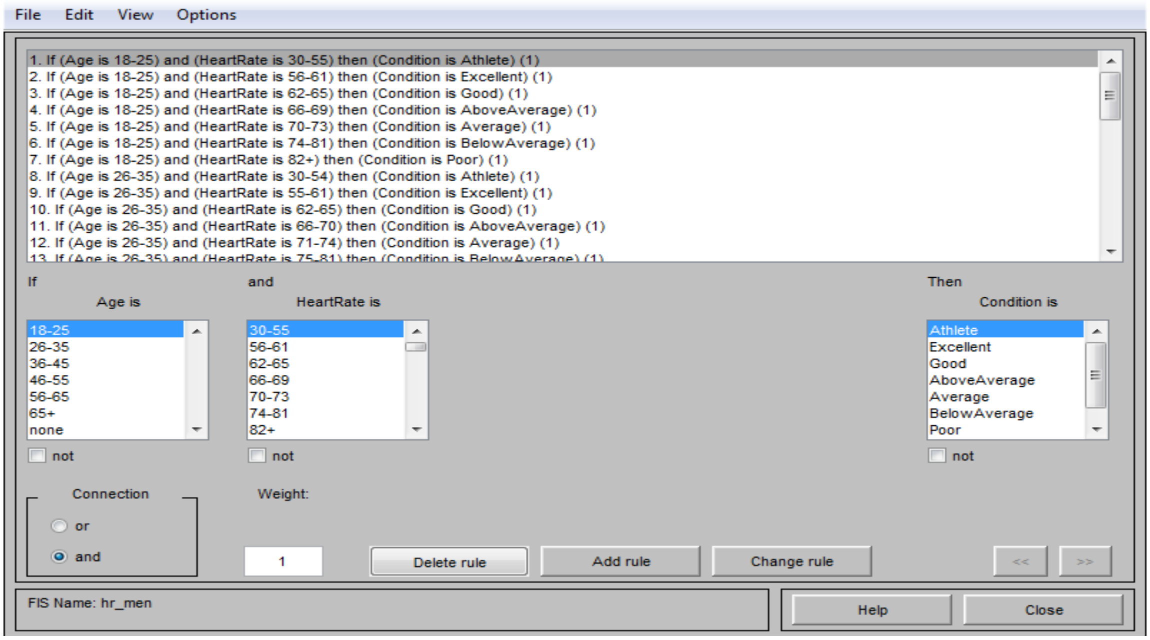

Figure 28: Rule Editor For Men Heart Rate Classification.

Figure 28 show the rule editor for men heart rate classification. There are in total of 42 rules used to classify the resting heart rate. The number of rule used in third simulation is less than the number of rules used in the second simulation.

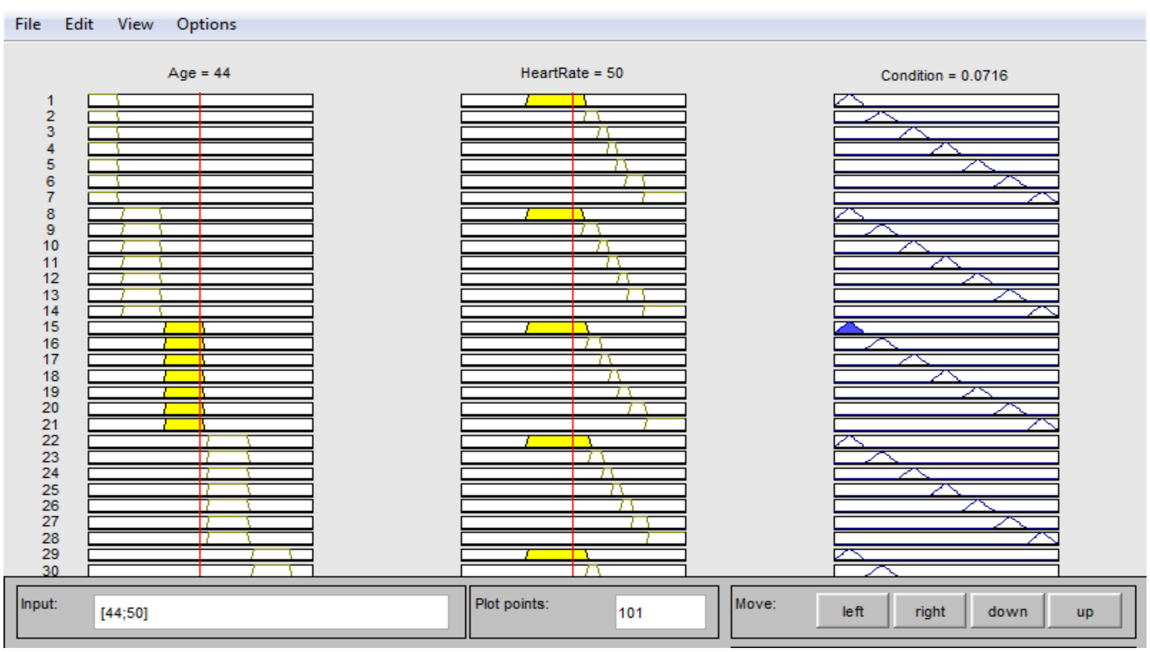

Figure 29: Rule Viewer For Resting Heart Rate Classification.

A set of graphical user interface (GUI) as shown in figure 30, 31 and 32 is created using Matlab by utilizing the dialog box capabilities. The introduction of GUI increase the efficiency and create a better interaction between user and the system. User are required to choose the gender of the test data and another GUI will appear as shown in figure 31. User are requested to insert the age and the heart rate data.

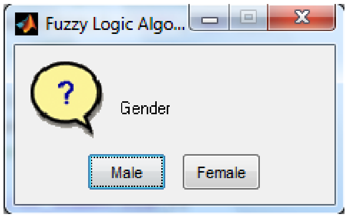

Figure 30: Graphic User Interface 1.

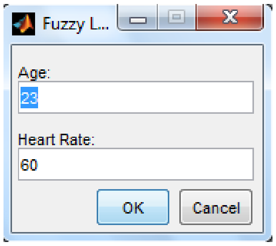

Figure 31: Graphic User Interface 2.

After all the input required is available, a final dialog box shows and display the condition or the output of the simulation. The coding for the interaction between fuzzy logic algorithm and GUI can be found in the appendix

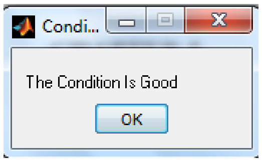

Figure 32: Graphic User Interface 3.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In conclusion, this project is able to classify the heart rate using fuzzy logic by developing the fuzzy logic algorithm using Fuzzy Logic Toolbox™ in MATLAB. The input for the fuzzy logic were taken from Zigbee module device and the data used into the MATLAB for classification. The heart rate was classified based on the number of pulse per minutes. The method used in the classification of the heart rate is Mamdani's method. The project was feasible and executed within the 8 month period.

From the three simulation, the progress of the project is acceptable and the result of the simulation is working according to the classification. The percentage of accuracy of classification is 100% when verified manually.

The algorithm of this study successfully classifies seven categories of resting heart rate condition for six ranges of ages, thus the objective of the project is achieved.

5.2. Recommendation

There are a few recommendations that could improve the functionality of the project. The project could be further improve by integrating the algorithm with the Zigbee module device and able to classify in real time. This will enable a direct monitoring with the patients.

The project can also be extended to classify the body heat and blood pressure data available from the Zigbee module device.

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APPENDICES

Appendix 1. Heart Rate Data

Table 14: Heart Rate For Male And Female Ages 18-25 In One Minute

Time (sec)	Male				Female			
	1st trial	2nd trial	3rd trial	Avg	1st trial	2nd trial	3rd trial	Avg
1	40	71	75	62	53	66	61	60
2	50	76	72	66	53	63	65	60
3	58	76	72	69	54	60	68	61
4	68	75	72	72	54	60	76	63
5	73	75	72	73	55	60	77	64
6	75	75	72	74	55	60	77	64
7	75	75	72	74	56	59	76	64
8	75	75	72	74	56	60	76	64
9	75	75	72	74	57	60	75	64
10	75	75	72	74	57	59	75	64
11	75	75	72	74	57	59	74	63
12	75	75	72	74	58	59	71	63
13	75	75	72	74	58	59	66	61
14	75	75	73	74	58	59	65	61
15	75	75	73	74	58	59	64	60
16	75	75	73	74	58	59	63	60
17	75	75	73	74	58	59	63	60
18	75	75	73	74	58	59	62	60
19	75	75	73	74	58	59	62	60
20	75	75	74	75	58	59	61	59
21	75	75	74	75	58	59	61	59
22	75	75	74	75	58	59	60	59
23	75	75	73	74	58	59	60	59
24	75	75	74	75	58	59	60	59
25	75	75	73	74	58	59	59	59
26	75	75	73	74	58	59	59	59
27	75	75	73	74	58	58	59	58
28	76	75	73	75	58	59	58	58
29	75	75	72	74	57	58	58	58

30	76	75	72	74	57	58	58	58
31	76	75	72	74	58	58	58	58
32	75	75	72	74	58	58	58	58
33	76	75	72	74	58	58	57	58
34	76	75	72	74	58	58	58	58
35	76	75	72	74	58	58	58	58
36	76	76	72	75	58	58	57	58
37	76	76	73	75	58	58	57	58
38	76	76	73	75	58	59	57	58
39	75	76	73	75	58	59	57	58
40	77	77	73	76	59	60	57	59
41	76	77	73	75	59	60	57	59
42	76	78	73	76	59	60	57	59
43	76	78	74	76	59	60	57	59
44	76	78	74	76	59	61	57	59
45	76	78	74	76	59	60	57	59
46	76	77	74	76	59	61	58	59
47	76	77	74	76	59	60	58	59
48	76	77	74	76	59	60	58	59
49	76	76	74	75	59	60	58	59
50	76	75	74	75	59	60	58	59
51	76	75	73	75	59	60	58	59
52	76	75	73	75	58	60	58	59
53	76	74	73	74	58	59	58	58
54	76	74	73	74	58	59	58	58
55	76	74	73	74	58	59	58	58
56	76	74	73	74	58	59	58	58
57	75	75	72	74	58	59	58	58
58	77	75	72	75	58	59	58	58
59	77	75	72	75	58	59	58	58
60	77	75	72	75	58	59	58	58

Table 15: Heart Rate For Male And Female Ages 26-35 In One Minute

Time (sec)	Male				Female			
	1st trial	2nd trial	3rd trial	Avg	1st trial	2nd trial	3rd trial	Avg
1	61	72	40	58	60	83	73	72
2	56	62	40	53	66	83	78	76
3	56	55	40	50	73	83	78	78
4	51	55	40	49	78	82	78	79
5	48	49	40	46	77	79	79	78
6	48	44	40	44	76	77	79	77
7	44	44	40	43	75	76	78	76
8	41	41	40	41	74	75	78	76
9	41	39	40	40	73	74	77	75
10	39	39	40	39	73	73	76	74
11	39	40	40	40	74	72	76	74
12	38	40	40	39	74	71	76	74
13	38	40	40	39	74	70	74	73
14	38	40	39	39	73	69	73	72
15	37	40	40	39	73	69	72	71
16	37	40	40	39	72	69	70	70
17	37	40	40	39	72	68	69	70
18	37	41	41	40	73	68	69	70
19	37	41	41	40	73	67	68	69
20	37	41	41	40	74	68	68	70
21	37	41	42	40	74	68	68	70
22	37	41	42	40	75	68	68	70
23	37	41	41	40	75	69	68	71
24	37	40	41	39	75	69	69	71
25	37	40	41	39	74	69	70	71
26	37	40	41	39	74	70	70	71
27	37	40	41	39	73	71	71	72
28	37	40	41	39	73	73	71	72
29	37	40	41	39	73	74	70	72
30	37	41	41	40	72	76	70	73
31	37	41	41	40	72	77	70	73
32	37	41	41	40	72	79	70	74
33	37	41	40	39	73	82	70	75

34	37	42	41	40	72	83	70	75
35	39	43	41	41	72	84	69	75
36	39	43	40	41	73	85	69	76
37	39	43	41	41	71	84	69	75
38	39	43	41	41	72	83	69	75
39	39	43	41	41	72	81	69	74
40	39	43	41	41	72	80	69	74
41	40	43	41	41	72	79	69	73
42	41	43	41	42	71	77	68	72
43	41	43	40	41	72	76	68	72
44	42	43	40	42	71	75	68	71
45	43	43	40	42	71	75	68	71
46	43	43	41	42	70	74	69	71
47	43	43	40	42	69	74	69	71
48	43	43	40	42	69	74	70	71
49	42	43	41	42	69	75	70	71
50	42	43	41	42	70	75	70	72
51	43	49	41	44	70	75	70	72
52	44	44	40	43	70	76	70	72
53	44	44	41	43	71	76	70	72
54	44	41	41	42	71	76	69	72
55	44	39	40	41	73	76	70	73
56	44	39	40	41	74	76	69	73
57	43	40	40	41	74	76	70	73
58	43	40	41	41	75	76	71	74
59	42	40	41	41	75	76	71	74
60	43	40	41	41	75	75	71	74

Table 16: Heart Rate For Male And Female Ages 36-45 In One Minute

Time (sec)	**Male**				**Female**			
	1st trial	**2nd trial**	**3rd trial**	**Avg**	**1st trial**	**2nd trial**	**3rd trial**	**Avg**
1	66	71	74	70	78	81	82	80
2	70	70	73	71	78	81	82	80
3	71	70	73	71	79	81	81	80
4	73	70	73	72	80	81	82	81
5	72	71	72	72	81	81	83	82
6	74	71	72	72	81	80	84	82
7	74	71	73	73	82	80	83	82
8	72	71	71	71	82	80	83	82
9	69	70	70	70	82	79	82	81
10	68	71	69	69	82	79	82	81
11	68	71	69	69	83	81	81	82
12	68	72	69	70	83	81	81	82
13	69	71	68	69	83	80	81	81
14	68	70	77	72	85	81	80	82
15	68	69	77	71	84	82	80	82
16	69	69	78	72	85	82	80	82
17	70	67	78	72	86	82	80	83
18	71	67	78	72	86	81	81	83
19	72	67	78	72	86	81	82	83
20	71	67	77	72	86	80	82	83
21	70	66	77	71	86	80	83	83
22	70	67	75	71	86	80	85	84
23	70	66	70	69	86	81	84	84
24	72	67	66	68	84	81	84	83
25	72	67	65	68	82	82	83	82
26	72	67	63	67	81	81	84	82
27	72	67	62	67	81	82	84	82
28	75	70	62	69	80	82	82	81
29	76	74	62	71	81	81	80	81
30	77	73	62	71	80	80	79	80
31	77	74	63	71	79	79	81	80
32	77	74	63	71	82	78	81	80
33	78	74	64	72	81	77	80	79

34	77	76	64	72	79	78	79	79
35	77	77	65	73	79	78	80	79
36	76	72	66	71	79	78	82	80
37	75	69	66	70	78	80	82	80
38	75	70	66	70	78	81	81	80
39	75	71	66	71	78	83	82	81
40	76	72	66	71	77	83	83	81
41	76	72	67	72	77	83	84	81
42	76	72	70	73	78	83	83	81
43	76	72	72	73	77	83	83	81
44	76	73	73	74	77	83	82	81
45	76	73	74	74	78	83	82	81
46	76	73	75	75	78	84	81	81
47	76	73	76	75	78	85	81	81
48	76	72	75	74	80	85	81	82
49	76	72	75	74	80	87	80	82
50	75	72	78	75	79	88	80	82
51	74	72	77	74	82	88	80	83
52	72	72	79	74	82	88	80	83
53	72	72	81	75	81	85	81	82
54	72	72	81	75	81	85	82	83
55	71	73	82	75	82	85	82	83
56	70	73	82	75	81	84	83	83
57	68	72	81	74	81	83	85	83

Table 17: Heart Rate For Male And Female Ages 46-55 In One Minute

Time (sec)	**Male**				**Female**			
	1st trial	**2nd trial**	**3rd trial**	**Avg**	**1st trial**	**2nd trial**	**3rd trial**	**Avg**
1	84	84	88	85	77	87	76	80
2	86	85	88	86	77	87	75	80
3	88	86	88	87	76	91	76	81
4	90	86	89	88	75	88	77	80
5	91	87	89	89	75	88	77	80
6	94	88	90	91	76	87	78	80
7	96	88	90	91	76	86	78	80
8	96	88	91	92	76	86	79	80
9	95	88	92	92	78	85	79	81
10	95	89	91	92	79	81	80	80
11	95	89	91	92	79	83	80	81
12	94	89	90	91	80	81	81	81
13	92	90	89	90	80	81	81	81
14	92	90	89	90	81	81	81	81
15	90	90	88	89	80	81	82	81
16	89	90	88	89	80	81	82	81
17	88	89	87	88	80	81	83	81
18	87	88	88	88	79	88	83	83
19	87	88	88	88	80	89	83	84
20	86	88	89	88	79	89	83	84
21	86	88	89	88	79	89	83	84
22	85	89	89	88	80	89	82	84
23	85	89	89	88	80	88	82	83
24	86	90	90	89	80	87	81	83
25	86	90	90	89	80	80	81	80
26	87	90	90	89	79	78	81	79
27	86	90	90	89	79	78	81	79
28	87	91	89	89	79	79	80	79
29	88	91	90	90	78	79	80	79
30	88	91	89	89	78	79	80	79
31	88	90	89	89	78	80	80	79
32	89	90	89	89	77	80	79	79
33	89	92	90	90	78	81	79	79

34	90	91	91	91	78	81	79	79
35	89	91	92	91	77	81	79	79
36	90	91	91	91	78	81	79	79
37	90	93	91	91	78	80	79	79
38	91	94	90	92	79	79	79	79
39	90	94	89	91	79	79	79	79
40	90	94	89	91	79	78	79	79
41	90	93	88	90	79	77	79	78
42	90	93	88	90	79	76	78	78
43	90	90	87	89	79	76	77	77
44	90	88	88	89	78	75	77	77
45	89	86	88	88	78	75	77	77
46	90	83	89	87	77	74	77	76
47	90	82	89	87	77	75	77	76
48	91	81	89	87	76	74	77	76
49	91	80	89	87	76	74	76	75
50	92	80	90	87	76	75	76	76
51	91	81	90	87	77	75	75	76
52	90	82	90	87	77	76	74	76
53	89	84	90	88	78	77	74	76
54	88	85	89	87	80	77	73	77
55	86	86	90	87	80	77	73	77
56	85	86	91	87	82	76	73	77
57	85	87	92	88	82	77	74	78
58	84	87	91	87	84	76	76	79
59	84	88	91	88	85	76	77	79
60	84	88	90	87	86	76	78	80

Table 18: Heart Rate For Male And Female Ages 56-65 In One Minute

Time (sec)	Male				Female			
	1st trial	2nd trial	3rd trial	Avg	1st trial	2nd trial	3rd trial	Avg
1	40	71	75	62	53	66	61	60
2	50	76	72	66	53	63	65	60
3	58	76	72	69	54	60	68	61
4	68	75	72	72	54	60	76	63
5	73	75	72	73	55	60	77	64
6	75	75	72	74	55	60	77	64
7	75	75	72	74	56	59	76	64
8	75	75	72	74	56	60	76	64
9	75	75	72	74	57	60	75	64
10	75	75	72	74	57	59	75	64
11	75	75	72	74	57	59	74	63
12	75	75	72	74	58	59	71	63
13	75	75	72	74	58	59	66	61
14	75	75	73	74	58	59	65	61
15	75	75	73	74	58	59	64	60
16	75	75	73	74	58	59	63	60
17	75	75	73	74	58	59	63	60
18	75	75	73	74	58	59	62	60
19	75	75	73	74	58	59	62	60
20	75	75	74	75	58	59	61	59
21	75	75	74	75	58	59	61	59
22	75	75	74	75	58	59	60	59
23	75	75	73	74	58	59	60	59
24	75	75	74	75	58	59	60	59
25	75	75	73	74	58	59	59	59
26	75	75	73	74	58	59	59	59
27	75	75	73	74	58	58	59	58
28	76	75	73	75	58	59	58	58
29	75	75	72	74	57	58	58	58
30	76	75	72	74	57	58	58	58
31	76	75	72	74	58	58	58	58
32	75	75	72	74	58	58	58	58
33	76	75	72	74	58	58	57	58

34	76	75	72	74	58	58	58	58
35	76	75	72	74	58	58	58	58
36	76	76	72	75	58	58	57	58
37	76	76	73	75	58	58	57	58
38	76	76	73	75	58	59	57	58
39	75	76	73	75	58	59	57	58
40	77	77	73	76	59	60	57	59
41	76	77	73	75	59	60	57	59
42	76	78	73	76	59	60	57	59
43	76	78	74	76	59	60	57	59
44	76	78	74	76	59	61	57	59
45	76	78	74	76	59	60	57	59
46	76	77	74	76	59	61	58	59
47	76	77	74	76	59	60	58	59
48	76	77	74	76	59	60	58	59
49	76	76	74	75	59	60	58	59
50	76	75	74	75	59	60	58	59
51	76	75	73	75	59	60	58	59
52	76	75	73	75	58	60	58	59
53	76	74	73	74	58	59	58	58
54	76	74	73	74	58	59	58	58
55	76	74	73	74	58	59	58	58
56	76	74	73	74	58	59	58	58
57	75	75	72	74	58	59	58	58
58	77	75	72	75	58	59	58	58
59	77	75	72	75	58	59	58	58
60	77	75	72	75	58	59	58	58

Appendix 2. Coding For Fuzzy Logic Algorithm And Graphic User Interface

```
clear all;
clc;

fprintf('Welcome To Fuzzy Logic Algorithm For Heart Rate Monitoring
\n')

% Construct a questdlg with three options
choice = questdlg('Gender','Fuzzy Logic
Algorithm','Male','Female','Male');
% Handle response
switch choice
    case 'Male'

prompt={'Age:','Heart Rate:'};
%Create all your text fields with the questions specified by the
variable prompt.
title='Fuzzy Logic Algorithm For Heart Rate Monitoring';
% The main title of your input dialog interface.
answer=inputdlg(prompt,title,1,{'23','60'});
% Default Answer '23', '60'

Age = str2num(answer{1});
Heartrate = str2num(answer{2});
% Convert these values to a number using str2num.

    fis = readfis('f:/hr_men.fis');
    out = evalfis([Age Heartrate],fis);

    if out < 0.0715
    %disp('The condition is athlete')
    h = msgbox('The Condition Is Athlete','Condition');
    elseif out<0.2145
    %disp('The condition is excellent')
    h = msgbox('The Condition Is Excellent','Condition');
    elseif out < 0.3575
    %disp('The condition is good')
    h = msgbox('The Condition Is Good','Condition');
    elseif out < 0.5005
    %disp('The condition is above average')
    h = msgbox('The Condition Is Above Average','Condition');
    elseif out < 0.6435
    %disp('The condition is average')
    h = msgbox('The Condition Is Average','Condition');
    elseif out < 0.7864
    %disp('The condition is below average')
    h = msgbox('The Condition Is Below Average','Condition');
    else
    %disp('The condition is poor')
    h = msgbox('The Condition Is Poor','Condition');
    %end
    end
```

```
    case 'Female'

prompt={'Age:','Heart Rate:'};
%Create all your text fields with the questions specified by the
variable prompt.
title='Fuzzy Logic Algorithm For Heart Rate Monitoring';
% The main title of your input dialog interface.
answer=inputdlg(prompt,title,1,{'23','60'});
% Default Answer '23', '60'

Age = str2num(answer{1});
Heartrate = str2num(answer{2});
% Convert these values to a number using str2num.

    fis = readfis('f:/hr_women.fis');
    out = evalfis([Age Heartrate],fis);

    if out < 0.0715
    %disp('The condition is athlete')
    h = msgbox('The Condition Is Athlete','Condition');
    elseif out<0.2145
    %disp('The condition is excellent')
    h = msgbox('The Condition Is Excellent','Condition');
    elseif out < 0.3575
    %disp('The condition is good')
    h = msgbox('The Condition Is Good','Condition');
    elseif out < 0.5005
    %disp('The condition is above average')
    h = msgbox('The Condition Is Above Average','Condition');
    elseif out < 0.6435
    %disp('The condition is average')
    h = msgbox('The Condition Is Average','Condition');
    elseif out < 0.7864
    %disp('The condition is below average')
    h = msgbox('The Condition Is Below Average','Condition');
    else
    %disp('The condition is poor')
    h = msgbox('The Condition Is Poor','Condition');
    %end
    end
end
```

Appendix 3. Fuzzy Logic Algorithm For Second Simulation

```
[System]
Name='heartcondition2'
Type='mamdani'
Version=2.0
NumInputs=3
NumOutputs=1
NumRules=60
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='Gender'
Range=[0 1]
NumMFs=2
MF1='male':'trapmf',[0 0 0.5 0.5]
MF2='female':'trapmf',[0.5 0.5 1 1]

[Input2]
Name='Age'
Range=[18 70]
NumMFs=6
MF1='18-25':'trapmf',[18 18 25 25]
MF2='26-35':'trapmf',[26 26 35 35]
MF3='36-45':'trapmf',[36 36 45 45]
MF4='46-55':'trapmf',[46 46 55 55]
MF5='56-65':'trapmf',[56 56 65 65]
MF6='65+':'trapmf',[66 66 70 70]

[Input3]
Name='HeartRate'
Range=[0 100]
NumMFs=35
MF1='30-55':'trapmf',[30 30 55 55]
MF2='56-61':'trapmf',[56 56 61 61]
MF3='62-65':'trapmf',[62 62 65 65]
MF4='66-81':'trapmf',[66 66 81 81]
MF5='82+':'trapmf',[82 82 100 100]
MF6='30-54':'trapmf',[30 30 54 54]
MF7='55-61':'trapmf',[55 55 61 61]
MF8='30-56':'trapmf',[30 30 56 56]
MF9='57-62':'trapmf',[57 57 62 62]
MF10='63-66':'trapmf',[63 63 66 66]
MF11='67-82':'trapmf',[67 67 82 82]
MF12='83+':'trapmf',[83 83 100 100]
MF13='30-57':'trapmf',[30 30 57 57]
MF14='58-63':'trapmf',[58 58 63 63]
MF15='64-67':'trapmf',[64 64 67 67]
MF16='68-83':'trapmf',[68 68 83 83]
MF17='84+':'trapmf',[84 84 100 100]
MF18='57-61':'trapmf',[57 57 61 61]
MF19='66-79':'trapmf',[66 66 79 79]
```

```
MF20='80+':'trapmf',[80 80 100 100]
MF21='30-60':'trapmf',[30 30 60 60]
MF22='61-65':'trapmf',[61 61 65 65]
MF23='66-69':'trapmf',[66 66 69 69]
MF24='70-84':'trapmf',[70 70 84 84]
MF25='85+':'trapmf',[85 85 100 100]
MF26='30-59':'trapmf',[30 30 59 59]
MF27='60-64':'trapmf',[60 60 64 64]
MF28='65-68':'trapmf',[65 65 68 68]
MF29='69-82':'trapmf',[69 69 82 82]
MF30='65-69':'trapmf',[65 65 69 69]
MF31='70-83':'trapmf',[70 70 83 83]
MF32='62-67':'trapmf',[62 62 67 67]
MF33='69-83':'trapmf',[69 69 83 83]
MF34='69-84':'trapmf',[69 69 84 84]
MF35='68-81':'trapmf',[68 68 81 81]

[Output1]
Name='Condition'
Range=[0 1]
NumMFs=5
MF1='Athlete':'trimf',[0 0.1 0.2]
MF2='Excellent':'trimf',[0.2 0.3 0.4]
MF3='Good':'trimf',[0.4 0.5 0.6]
MF4='Average':'trimf',[0.6 0.7 0.8]
MF5='Poor':'trimf',[0.8 0.9 1]

[Rules]
1 1 1, 1 (1) : 1
1 1 2, 2 (1) : 1
1 1 3, 3 (1) : 1
1 1 4, 4 (1) : 1
1 1 5, 5 (1) : 1
1 2 6, 1 (1) : 1
1 2 7, 2 (1) : 1
1 2 3, 3 (1) : 1
1 2 4, 4 (1) : 1
1 2 5, 5 (1) : 1
1 3 8, 1 (1) : 1
1 3 9, 2 (1) : 1
1 3 10, 3 (1) : 1
1 3 11, 4 (1) : 1
1 3 12, 5 (1) : 1
1 4 13, 1 (1) : 1
1 4 14, 2 (1) : 1
1 4 15, 3 (1) : 1
1 4 16, 4 (1) : 1
1 4 17, 5 (1) : 1
1 5 8, 1 (1) : 1
1 5 18, 2 (1) : 1
1 5 32, 3 (1) : 1
1 5 35, 4 (1) : 1
1 5 5, 5 (1) : 1
1 6 1, 1 (1) : 1
1 6 2, 2 (1) : 1
1 6 3, 3 (1) : 1
1 6 19, 4 (1) : 1
```

```
1 6 20, 5 (1) : 1
2 1 21, 1 (1) : 1
2 1 22, 2 (1) : 1
2 1 23, 3 (1) : 1
2 1 24, 4 (1) : 1
2 1 25, 5 (1) : 1
2 2 26, 1 (1) : 1
2 2 27, 2 (1) : 1
2 2 28, 3 (1) : 1
2 2 29, 4 (1) : 1
2 2 12, 5 (1) : 1
2 3 26, 1 (1) : 1
2 3 27, 2 (1) : 1
2 3 30, 3 (1) : 1
2 3 24, 4 (1) : 1
2 3 25, 5 (1) : 1
2 4 21, 1 (1) : 1
2 4 22, 2 (1) : 1
2 4 23, 3 (1) : 1
2 4 31, 4 (1) : 1
2 4 17, 5 (1) : 1
2 5 26, 1 (1) : 1
2 5 27, 2 (1) : 1
2 5 28, 3 (1) : 1
2 5 33, 4 (1) : 1
2 5 17, 5 (1) : 1
2 6 26, 1 (1) : 1
2 6 27, 2 (1) : 1
2 6 28, 3 (1) : 1
2 6 34, 4 (1) : 1
2 6 17, 5 (1) : 1
```

Appendix 4. Fuzzy Logic Algorithm For Third Simulation

```
[System]
Name='hr_men'
Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=1
NumRules=42
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='Age'
Range=[18 70]
NumMFs=6
MF1='18-25':'trapmf',[18 18 25 25]
MF2='26-35':'trapmf',[26 26 35 35]
MF3='36-45':'trapmf',[36 36 45 45]
MF4='46-55':'trapmf',[46 46 55 55]
MF5='56-65':'trapmf',[56 56 65 65]
MF6='65+':'trapmf',[66 66 70 70]

[Input2]
Name='HeartRate'
Range=[0 100]
NumMFs=42
MF1='30-55':'trapmf',[30 30 55 55]
MF2='56-61':'trapmf',[56 56 61 61]
MF3='62-65':'trapmf',[62 62 65 65]
MF4='66-69':'trapmf',[66 66 69 69]
MF5='70-73':'trapmf',[70 70 73 73]
MF6='74-81':'trapmf',[74 74 81 81]
MF7='82+':'trapmf',[82 82 100 100]
MF8='30-54':'trapmf',[30 30 54 54]
MF9='55-61':'trapmf',[55 55 61 61]
MF10='62-65':'trapmf',[62 62 65 65]
MF11='66-70':'trapmf',[66 66 70 70]
MF12='71-74':'trapmf',[71 71 74 74]
MF13='75-81':'trapmf',[75 75 81 81]
MF14='82+':'trapmf',[82 82 100 100]
MF15='30-56':'trapmf',[30 30 56 56]
MF16='57-62':'trapmf',[57 57 62 62]
MF17='63-66':'trapmf',[63 63 66 66]
MF18='67-70':'trapmf',[67 67 70 70]
MF19='71-75':'trapmf',[71 71 75 75]
MF20='76-82':'trapmf',[76 76 82 82]
MF21='83+':'trapmf',[83 83 100 100]
MF22='30-57':'trapmf',[30 30 57 57]
MF23='58-63':'trapmf',[58 58 63 63]
MF24='64-67':'trapmf',[64 64 67 67]
MF25='68-71':'trapmf',[68 68 71 71]
MF26='72-76':'trapmf',[72 72 76 76]
```

```
MF27='77-83':'trapmf',[77 77 83 83]
MF28='84+':'trapmf',[84 84 100 100]
MF29='30-56':'trapmf',[30 30 56 56]
MF30='57-61':'trapmf',[57 57 61 61]
MF31='62-67':'trapmf',[62 62 67 67]
MF32='68-71':'trapmf',[68 68 71 71]
MF33='72-75':'trapmf',[72 72 75 75]
MF34='76-81':'trapmf',[76 76 81 81]
MF35='82+':'trapmf',[82 82 100 100]
MF36='30-55':'trapmf',[30 30 55 55]
MF37='56-61':'trapmf',[56 56 61 61]
MF38='62-65':'trapmf',[62 62 65 65]
MF39='66-69':'trapmf',[66 66 69 69]
MF40='70-73':'trapmf',[70 70 73 73]
MF41='74-79':'trapmf',[74 74 79 79]
MF42='80+':'trapmf',[80 80 100 100]

[Output1]
Name='Condition'
Range=[0 1]
NumMFs=7
MF1='Athlete':'trimf',[0 0.0715 0.143]
MF2='Excellent':'trimf',[0.143 0.2145 0.286]
MF3='Good':'trimf',[0.286 0.3575 0.429]
MF4='AboveAverage':'trimf',[0.429 0.5005 0.572]
MF5='Average':'trimf',[0.572 0.6435 0.715]
MF6='BelowAverage':'trimf',[0.715 0.7865 0.858]
MF7='Poor':'trimf',[0.858 0.9295 1]

[Rules]
1 1, 1 (1) : 1
1 2, 2 (1) : 1
1 3, 3 (1) : 1
1 4, 4 (1) : 1
1 5, 5 (1) : 1
1 6, 6 (1) : 1
1 7, 7 (1) : 1
2 8, 1 (1) : 1
2 9, 2 (1) : 1
2 10, 3 (1) : 1
2 11, 4 (1) : 1
2 12, 5 (1) : 1
2 13, 6 (1) : 1
2 14, 7 (1) : 1
3 15, 1 (1) : 1
3 16, 2 (1) : 1
3 17, 3 (1) : 1
3 18, 4 (1) : 1
3 19, 5 (1) : 1
3 20, 6 (1) : 1
3 21, 7 (1) : 1
4 22, 1 (1) : 1
4 23, 2 (1) : 1
4 24, 3 (1) : 1
4 25, 4 (1) : 1
4 26, 5 (1) : 1
4 27, 6 (1) : 1
```

```
4 28, 7 (1) : 1
5 29, 1 (1) : 1
5 30, 2 (1) : 1
5 31, 3 (1) : 1
5 32, 4 (1) : 1
5 33, 5 (1) : 1
5 34, 6 (1) : 1
5 35, 7 (1) : 1
6 36, 1 (1) : 1
6 37, 2 (1) : 1
6 38, 3 (1) : 1
6 39, 4 (1) : 1
6 40, 5 (1) : 1
6 41, 6 (1) : 1
6 42, 7 (1) : 1
```

```
[System]
Name='hr_women'
Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=1
NumRules=0
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='Age'
Range=[18 70]
NumMFs=6
MF1='18-25':'trapmf',[18 18 25 25]
MF2='26-35':'trapmf',[26 26 35 35]
MF3='36-45':'trapmf',[36 36 45 45]
MF4='46-55':'trapmf',[46 46 55 55]
MF5='56-65':'trapmf',[56 56 65 65]
MF6='65+':'trapmf',[66 66 70 70]

[Input2]
Name='HeartRate'
Range=[0 100]
NumMFs=42
MF1='30-60':'trapmf',[30 30 60 60]
MF2='61-65':'trapmf',[61 61 65 65]
MF3='66-69':'trapmf',[66 66 69 69]
MF4='70-73':'trapmf',[70 70 73 73]
MF5='74-78':'trapmf',[74 74 78 78]
MF6='79-84':'trapmf',[79 79 84 84]
MF7='85+':'trapmf',[85 85 100 100]
MF8='30-59':'trapmf',[30 30 59 59]
MF9='60-64':'trapmf',[60 60 64 64]
MF10='65-68':'trapmf',[65 65 68 68]
MF11='69-72':'trapmf',[69 69 72 72]
MF12='73-76':'trapmf',[73 73 76 76]
MF13='77-82':'trapmf',[77 77 82 82]
MF14='83+':'trapmf',[83 83 100 100]
MF15='30-59':'trapmf',[30 30 59 59]
MF16='60-64':'trapmf',[60 60 64 64]
MF17='65-69':'trapmf',[65 65 69 69]
MF18='70-73':'trapmf',[70 70 73 73]
MF19='74-78':'trapmf',[74 74 78 78]
MF20='79-84':'trapmf',[78 78 84 84]
MF21='85+':'trapmf',[85 85 100 100]
MF22='30-60':'trapmf',[30 30 60 60]
MF23='61-65':'trapmf',[61 61 65 65]
MF24='66-69':'trapmf',[66 66 69 69]
MF25='70-73':'trapmf',[70 70 73 73]
MF26='74-77':'trapmf',[74 74 77 77]
MF27='78-83':'trapmf',[78 78 83 83]
MF28='84+':'trapmf',[84 84 100 100]
MF29='30-59':'trapmf',[30 30 59 59]
```

```
MF30='60-64':'trapmf',[60 60 64 64]
MF31='65-68':'trapmf',[65 65 68 68]
MF32='69-73':'trapmf',[69 69 73 73]
MF33='74-77':'trapmf',[74 74 77 77]
MF34='78-83':'trapmf',[78 78 83 83]
MF35='84+':'trapmf',[84 84 100 100]
MF36='30-59':'trapmf',[30 30 59 59]
MF37='60-64':'trapmf',[60 60 64 64]
MF38='65-68':'trapmf',[65 65 68 68]
MF39='69-72':'trapmf',[69 69 72 72]
MF40='73-76':'trapmf',[73 73 76 76]
MF41='77-83':'trapmf',[77 77 83 83]
MF42='84+':'trapmf',[84 84 100 100]

[Output1]
Name='Condition'
Range=[0 1]
NumMFs=7
MF1='Athlete':'trimf',[0 0.0715 0.143]
MF2='Excellent':'trimf',[0.143 0.2145 0.286]
MF3='Good':'trimf',[0.286 0.3575 0.429]
MF4='AboveAverage':'trimf',[0.429 0.5005 0.572]
MF5='Average':'trimf',[0.572 0.6435 0.715]
MF6='BelowAverage':'trimf',[0.715 0.7865 0.858]
MF7='Poor':'trimf',[0.858 0.9295 1]

[Rules]
1 1, 1 (1) : 1
1 2, 2 (1) : 1
1 3, 3 (1) : 1
1 4, 4 (1) : 1
1 5, 5 (1) : 1
1 6, 6 (1) : 1
1 7, 7 (1) : 1
2 8, 1 (1) : 1
2 9, 2 (1) : 1
2 10, 3 (1) : 1
2 11, 4 (1) : 1
2 12, 5 (1) : 1
2 13, 6 (1) : 1
2 14, 7 (1) : 1
3 15, 1 (1) : 1
3 16, 2 (1) : 1
3 17, 3 (1) : 1
3 18, 4 (1) : 1
3 19, 5 (1) : 1
3 20, 6 (1) : 1
3 21, 7 (1) : 1
4 22, 1 (1) : 1
4 23, 2 (1) : 1
4 24, 3 (1) : 1
4 25, 4 (1) : 1
4 26, 5 (1) : 1
4 27, 6 (1) : 1
4 28, 7 (1) : 1
5 29, 1 (1) : 1
5 30, 2 (1) : 1
```

```
5 31, 3 (1) : 1
5 32, 4 (1) : 1
5 33, 5 (1) : 1
5 34, 6 (1) : 1
5 35, 7 (1) : 1
6 36, 1 (1) : 1
6 37, 2 (1) : 1
6 38, 3 (1) : 1
6 39, 4 (1) : 1
6 40, 5 (1) : 1
6 41, 6 (1) : 1
6 42, 7 (1) : 1
```